A STUDY OF THE ONTARIO FERROUS METAL SHREDDING INDUSTRY

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Report prepared for:

Waste Management Branch
Ontario Ministry of the Environment

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Report prepared for:

Waste Management Branch
Ontario Ministry of the Environment

In consultation with

The Canadian Association of Recycling Industries

Report prepared by:

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ABSTRACT

The report was commissioned to examine the ferrous metal shredding industry in Ontario with respect to the wastes arising from the processes involved. An overview of the ferrous metal shredding industry in Ontario is presented, followed by a study of the feedstream components to predict any possible hazardous contaminants in the waste (known as "fluff"). Also presented in the report are alternatives for management and disposal of waste from this industry, based on both existing and emerging technology.

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EXECUTIVE SUMMARY

The primary industry involved in the recovery of some 0.5 million tonnes of iron and steel from discarded automobiles in Ontario is the ferrous metal shredding industry. Through this process, another 0.1 million tonnes of iron and steel are also recovered from discarded domestic appliances, referred to as white goods, as well as miscellaneous steel scrap.

To facilitate the separation of iron and steel, feedstream components are conveyed through a large hammermill, where they are reduced to fist-sized fragments. Magnetic separation is used to recover the iron and steel fragments. The remaining material is processed either using air, water or mechanical separation to recover the non-ferrous metals. The waste material, referred to as shredder fluff, is composed of organics, such as plastics, foams, rubber, and well as inorganic materials, including glass and dirt. A typical automobile feedstream will result in a weight breakdown that is 75 percent iron and steel scrap, 2 to 5 percent non-ferrous metals and 20 to 23 percent fluff.

Since the shredder fluff stream is primarily made of organic polymeric materials, it is relatively non-biodegradable. Historically and presently, sanitary landfills have been used for the ultimate disposal of the fluff.

Recent concern associated with the disposal of shredder fluff are two-fold. Firstly, the non-hazardous nature of the waste has been questioned in some instances. Secondly, the lessening of available landfill capacity in Ontario and higher disposal costs make landfilling an increasingly undesirable method of disposal.

The shredding industry in Ontario plays a major role not only as the largest steel recycler, but also as generator of a significant portion of feedstream materials for the Ontario steelmaking industry. Thus, the implications of designating shredder fluff as hazardous, or of the unavailability of economically feasible disposal options would be serious. Therefore, the Ontario Ministry of the Environment and the Canadian Association of Recycling Industries (CARI) retained CH2M HILL Engineering Ltd. to conduct a study of the Ontario ferrous metal shredding industry. The primary purposes of the study were to determine more clearly the components of the ferrous metal recycling industry feedstream and to review the options for appropriate management and disposal of shredder wastes.

REVIEW OF ONTARIO SHREDDING INDUSTRY

A review of the industry was conducted using telephone surveys and on-site visits. In Ontario, there are eight operating shredding facilities, with capacities ranging from 50,000 to 360,000 tonnes per year of steel scrap output. The largest portion of feedstream components to most facilities is automobiles and autoparts. Only three facilities

presently accept white goods, and most facilities process some miscellaneous steel scrap.

Approximately 140,000 tonnes of shredder fluff, equivalent to 440,000 m^3 of landfill volume, requires disposal in Ontario each year. All of the shredding facilities landfill the waste materials. One facility is using an experimental dedicated landfill on their property, which is presently undergoing an Environmental Assessment for approval to operate on a permanent basis. Two facilities in Hamilton do not have access to a local landfill for disposal, since the formerly used site reached capacity, and are therefore, shredding only small quantities and stockpiling fluff. The others use local municipal landfills.

SHREDDER WASTE CONTAMINANTS

Previous studies (Clayton, 1980; ECO Research, 1988; SENES Consultants, 1988; Apotheker, 1989) carried out to characterize shredder fluff were reviewed as part of the study to identify which contaminants are present in the fluff that may result in a hazardous waste characterization according to the Ontario Regulation 309. Through this evaluation, only cadmium, lead and PCBs were identified as potential contaminants of concern. Leachate extracted from some samples taken in 1980 in the U.S. contained levels of cadmium and lead exceeded the Regulation 309 hazardous waste criteria. Furthermore, a number of reports from various U.S. locations indicate that the total PCB content of some fluff samples exceeds the hazardous waste criterion.

FEEDSTREAM COMPONENTS

Automobiles/Auto Parts

About 75 percent of the 580,000 tonnes of automobiles discarded each year in Ontario is recoverable as steel scrap. Non-magnetic metals, primarily aluminum, copper and zinc, account for about 5 percent of the vehicles weight. The use of zinc has decreased over time, while aluminum use has increased.

Lead is present in batteries, battery cable clamps, lead wheel weights and coatings and fillers of older cars. Also, lead deposits are present in the exhaust trains of vehicles which used leaded gasoline. Cadmium and lead have both been used in coatings and fillers. The use of cadmium has been discontinued, and lead use has decreased.

The organic polymeric materials content of automobiles has risen in the last two decades as the steel content has decreased. Approximately 100 kg of the vehicle's weight is attributed to plastics in 1980s automobiles. A broad range of types of organic materials is present in automobiles.

White Goods

Approximately 95,000 tonnes of white goods are available for disposal in Ontario each year. About 82 percent of this weight can be recovered as steel scrap. Of the remaining 18 percent, approximately eight percent can be recovered in a non-ferrous metal stream. The waste stream consists of organic polymeric materials (7 percent), and inorganic non-metallic materials such as glass, paper and dirt (3 percent).

Suspected materials that contribute contaminants to the appliance shredder fluff stream are lead flakes from solder, and paints and coatings that flake from the steel during shredding. Also, PCBs in capacitors in discarded appliances manufactured prior to 1977 are another potential source of contamination of fluff. Approximately 15 to 20 percent of discarded appliances contain capacitors which may contain PCBs. It is estimated that 50 percent of appliances with PCB capacitors will be discarded by 1993, and PCB capacitors will be present at a decreasing proportion for at least another 13 years.

WASTE MANAGEMENT ALTERNATIVES

Information on various techniques used to control the levels of the contaminants of concern in the shredder fluff were reviewed. These included:

- Control of materials entering the feedstream. Shredders could require that PCB capacitors, lead components (batteries, exhaust trains, etc.) be removed by the supplier prior to processing. Methods to control feedstream materials can also be used to prevent other undesirable materials, such as dangerous and extraneous items, from entering the shredder.

- Treatment of the fluff to stabilize or encapsulate the target contaminants prior to landfilling. Stabilization and encapsulation is used in California. Treatability work would be required for Ontario shredder fluff.

- Mechanical screening of the fluff, to remove fines. These fines are thought to contain the largest portion of metal and paint flakes. Experimental work is required to determine the effectiveness of this process.

- Monitoring of the fluff on a continuing basis to provide a statistical definition of the characteristics of the heterogeneous fluff stream, and to identify changing shredder fluff characteristics.

WASTE DISPOSAL ALTERNATIVES

An information search was carried out to identify presently used or potential fluff recycling or disposal alternatives. The following alternatives were identified:

- Landfilling of the fluff has been the most economically feasible alternative. However due to the rising costs of landfilling and the shortage of landfill capacities, this alternative may not be available to shredders in the long term.

- One study has shown that using fluff, or some portion of the fluff, as landfill cover material has many advantages over soil. This method is used for fluff from one shredder in Alberta and another in Wisconsin, U.S., and was used until recently in the Region of Ottawa-Carleton. When more information is available on the levels of contaminants in the fluff, this option could be considered for Ontario shredding facilities, particularly those situated near landfills that have a shortage of cover materials.

- One Ontario shredding facility is demonstrating that operating an on-site landfill dedicated to shredder wastes is technically feasible. The main advantage of this disposal method is the potential for recovery of the wastes for recycling or ultimate disposal, if a viable solution becomes available in the future. This option may not be available to all Ontario shredders, because a large area of land is required. Furthermore, the Environmental Assessment process required for the approval of an on-site disposal system is likely to be costly.

- Recycling methods identified for the organic polymeric portion of the waste stream were reviewed. Only mixed plastics recycling is thought to be technologically viable, however the economic feasibility is uncertain at this time.

- Hydrogenation and pyrolysis are both technologies that are being investigated for the recovery of valuable oils and fuel gases from the mixed waste stream. The applications of these technologies to shredder fluff are in the research stage, but show promise as potential future solutions.

- The incinerability of shredder fluff has been demonstrated by a number of researchers. Tests have been carried out in the Region of Hamilton Wentworth to determine whether this material can be burned in the Region's municipal incinerator. Results indicated that incineration would be a feasible alternative if modifications to the materials handling elements of the facility were implemented.

A number of researchers have studied and, in some cases proven, technological feasibility of a number of incineration/energy recovery processes for shredder fluff. Several issues, including siting, ownership, etc. would require consideration if any of these technologies are to be used by the Ontario shredding industry.

- Studies carried out in Europe have shown that the energy rich portion of shredder fluff (accounting for about 50 percent of the fluff weight) can be used as fuel supplement in the cement manufacturing process. This solution offers many advantages to both the shredder and the cement manufacturer. In Ontario, if this option is to be considered, further testing is required and incentives to the cement manufacturer must be created.

- A potential long term disposal solution may be upstream reduction of materials that would end up in the shredder fluff stream. This will depend on the incentives created for manufacturers of automobiles and white goods to design products for recycling.

Chapter 1
INTRODUCTION

1.1 BACKGROUND

1.1.1 Historical Development of Ferrous Shredding

The U.S. automotive industry consumes 20 percent of the steel, 33 to 35 percent of the zinc, about 10 percent of the copper and aluminum, 50 to 70 percent of the rubber and about 5 percent of the plastics used in the United States. Approximately 8 million cars with a total steel content of more than 6 million tonnes are discarded each year in the U.S. In addition, more than 29 million household appliances are scrapped each year, with a total steel content of about 1.8 million tonnes. In Canada, there are about 1.4 million tonnes of steel recoverable from automobile and appliance wastes each year, and in Ontario alone, about 0.5 million tonnes.

For many years, the ferrous scrap industry has recycled scrapped cars, with the primary incentive being the recovery of iron and steel. Until about the mid-sixties, most junk cars were processed by a variety of operations that included hand dismantling and sorting, incineration, shearing and baling. Because of the detrimentally high non-ferrous metal content in the steel produced using these methods, a volatility in demand resulted. When total demand for steel scrap was low, scrap from automobiles was among the first varieties eliminated from consideration by the scrap consumer.

The scrap shredder was introduced into the automobile recycling system in the early 1960s. This method involves the fragmentation or shredding of partially stripped automobiles, followed by separation of light wastes and magnetic separation of non-ferrous metals, to produce fist-sized steel chunks. Due to the improved purity of the iron and steel scrap produced, shredded scrap could be consumed by traditional and ministeel mills, in addition to the cupola furnaces of the iron foundry.

The automobile shredder also facilitated the economic separation and recovery of the non-metallic materials, thus improving considerably the total profitability of the process.

Until more recently, many steel operators held that the variety of materials contained in major appliances required extensive processing to obtain quality scrap for steelmaking. A study carried out in 1978 (Kinne) showed that discarded household appliances processed by shredding followed by air and magnetic separation produced a scrap with quality at least equal to shredder scrap from automobiles. Furthermore, the appliances shred uniformly in an automobile shredder, with no heavy power load surges of the equipment.

In a 1984 survey of world shredder capacity (Mat. Rec. Week., Sept, 1984), it was found that the capacity of the shredding industry exceeds the material supply from automobiles. It was noted that the overcapacity problem is not one of a shortage of supply, but of an increase in the number of shredder installations. However, the value of appliances and other miscellaneous steel scrap have been recognized by shredders, and these materials are included in the feedstream to many shredder operations. It is estimated that in North America, approximately 10 to 20 percent of the total feedstream tonnage is made up of appliances, and other miscellaneous steel scrap.

From the introduction of the ferrous metal shredding process in the 1960s, to the most recent comprehensive survey in 1984, the development of the industry has been rapid. In 1984, there were a world total number of 466 shredding facilities, including 158 in Europe, 84 in Japan and 202 in North America. The U.S. has the largest shredding capacity of 13.3 million tonnes (as shredded steel output) per year. In Canada, in 1984, there were 22 facilities, with a total output capacity of 1.2 million tonnes per year. Presently, the capacity of eight operating facilities in Ontario is 0.9 million tonnes per year.

The shredding industry has virtually taken over the ferrous metal recycling industry. Where once all recycled automobiles were baled, now it is estimated more that 90 percent of the discarded automobiles in North America serve as feed for shredding facilities. In Ontario, about 450,000 tonnes of auto scrap are produced annually by shredders. Furthermore, approximately 25 percent of white goods equivalent to 22,000 tonnes of steel scrap, are processed by shredding in Ontario. The remaining 75 percent are generally landfilled with municipal wastes, stockpiled, or are recycled in other processes (ie. baling).

1.1.2 Description of Shredder Operation

White goods, flattened and unflattened automobiles and miscellaneous scrapped steel items arriving at the shredder facility from the supplier are stockpiled. The feed components are lifted individually by a crane onto a conveyor, which sends each item through a large hammermill, where it is reduced to fragments, most of which are under 10 cm in major dimension. Three types of processes are used in Ontario to separate the lighter waste from the shredded iron and steel fragments. Figures 1.1 presents a process flow schematic of a typical automobile shredder using air separation.

Air Separation

The most commonly used process in Ontario involves air separation. The light material, consisting mainly of fibrous and other organic materials, is swept from the shredder output by a stream of air, and collected in cyclones. The stream of heavier material is conveyed further to undergo magnetic separation to recover the iron and steel. The non-magnetic residue, consisting primarily of non-ferrous metals but also

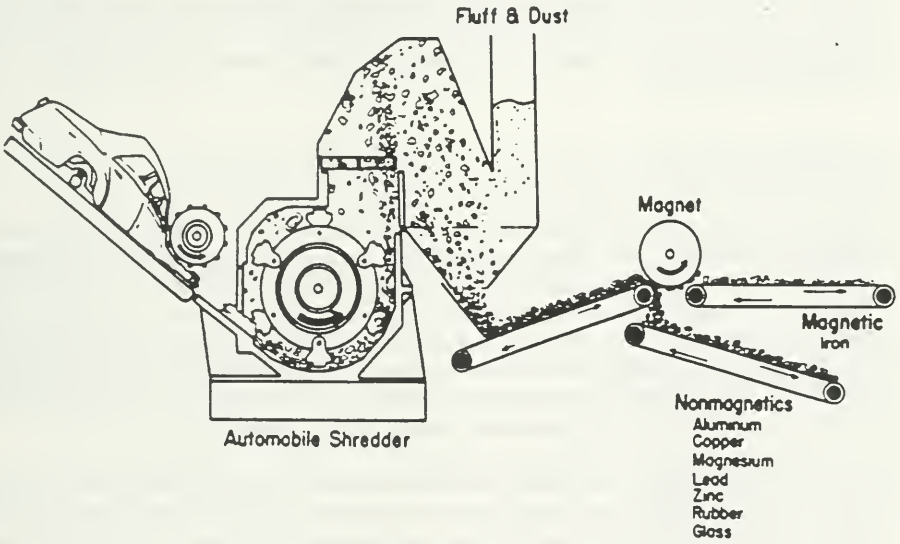

Figure 1.1
DIAGRAM OF
A TYPICAL AUTOMOBILE SHREDDER

CH2M HILL

including glass, rubber, etc. is stockpiled and shipped to a firm that specializes in processing the residues for non-ferrous metal recovery.

Water Separation

A second process is very similar to above, however separation of the lighter material occurs in a water tank. This method provides a large energy savings compared to air separation. However, the waste stream requiring disposal is significantly heavier resulting in higher disposal costs. In addition, this method cannot be used in the colder months when the water can freeze.

The shredded material is conveyed to a water tank, where water flows continuously upward. The lighter fraction floats, and is pushed off the surface onto an exiting conveyer by new material coming in. The denser fraction sinks to the bottom, where it is released and stockpiled. The water chamber vibrates to encourage separation of light and heavy fragments.

Mechanical Separation

In the third process, shredded material undergoes magnetic separation immediately upon exiting the shredder. Two streams result; the ferrous scrap and a stream containing non-metallic materials, including light organic wastes and non-ferrous metals. This stream is processed through a rotating screen, where fine particles, including dirt and glass, are removed. The remaining material travels on a conveyer past an air blower, where the lighter materials are blown onto one pile and the heavier materials remain. The heavy stream passes through a second magnetic separator to remove tramp ferrous fragments. The remaining non-ferrous stream is stock-piled.

Normally, automobiles entering the shredder have been manually stripped of items that have inherent market value, such as batteries and radiators. In addition, shredder facilities may refuse certain "non-conforming" items such as tires and fuel tanks, and these must also be removed prior to shredding. At present, white goods are not manually processed in Ontario prior to shredding.

1.1.3 Description and Impact of Shredder Residues

In each type of separation process, a "lighter" fraction of non-metallic material is left behind after the ferrous and non-ferrous materials are recovered. This fraction, consisting of organics, such as plastics, foams, rubber, as well as inorganic materials including glass and dirt, is referred to as "fluff".

The shredder fluff stream presently comprises an estimated 20 to 25 percent of the feed stream weight. This translates to an approximate weight of 0.2 to 0.3 million tonnes of fluff per year requiring ultimate disposal in Canada and 0.1 to 0.2 million tonnes in Ontario.

Since the shredder fluff stream consists primarily of organic polymeric materials, it is relatively non-biodegradable. Historically and presently, sanitary landfills have been the ultimate disposal method used for the fluff.

1.2 RATIONAL FOR STUDY

Recent concerns associated with the disposal of shredder fluff are two-fold. Firstly, the non-hazardous nature of this waste has recently been questioned in some instances. Secondly, the lessening of available landfill capacity in Ontario and higher disposal costs make landfilling an increasingly unsatisfactory and potentially unavailable method of disposal.

The Ontario Ministry of the Environment (MOE) has recently performed limited leachate and bulk analyses on samples of shredder fluff. The results from some samples suggest that concentrations of some heavy metals, such as cadmium and lead, as well as PCB, may be cause for concern. Although the results were inconclusive, the possibility that some of these wastes might be considered hazardous in accordance with Ontario Regulation 309 cannot be ruled out.

Historically, all Ontario shredding facilities have disposed of shredder wastes in municipal landfills. Tipping fees for disposal have, however, increased significantly in recent years. The landfill site serving the municipality of Hamilton has increased its tipping fees from $22/tonne to $110/tonne in the past five years. The municipal site for Toronto is presently $85/tonne, up from $64/tonne in 1989. Similar increases have been experienced in northern communities as well, though the tipping fees are much lower. The municipal landfill site in the Ottawa Region has increased from $33/tonne to $43/tonne in the past year, whereas Thunder Bay's tipping fees have increase from $5/tonne to $15/tonne in the past five years. As tipping fees continue to rise, the profit margin to the shredder who is recycling the steel decreases.

In the event that this waste would require management as a hazardous waste, the implications are serious. Hazardous waste disposal is prohibitively expensive and would thus reduce significantly the profit margin of the shredder. Furthermore, with the retention of the non-hazardous waste classification, economically feasible disposal options for shredder fluff are required.

Therefore, with the potential hazardous waste classification or the possible elimination of economically feasible disposal options, a scenario could be postulated in which the shredding industry in Ontario could be forced to shut-down. This occurred in California when the State designated all shredder wastes to be hazardous.

The shut-down of Ontario facilities could lead to two possible outcomes:

- A new disposal method would have to be found for the approximately 350,000 automobiles discarded in the Province each year.

- Since all shredder locations in Ontario are reasonably close to U.S. borders, it is feasible that the U.S. shredding industry would absorb the Ontario market. This could have serious economic implication to the Ontario steel-making industry, since shredded steel, accounting for about 20 percent of steel produced, would need to be purchased from the U.S.

Historically, very little research has been carried out to identify alternative disposal methods for shredder fluff. However, due to a growing concern in the industry over the hazardous contaminants in the waste stream, and the dwindling landfill capacity, alternatives must be considered for the Ontario shredding industry.

In response to the above problems, the MOE and the Canadian Association of Recycling Industries (CARI) have identified the need for this study of the Ontario ferrous metal shredding industry. The primary purposes of this study are to determine more clearly the components of the ferrous metal recycling industry feedstream and to review the options for appropriate management of shredder wastes.

1.3 STUDY OBJECTIVES

As outlined in the Request for Proposal (RFP) which initiated this study, (see Appendix A), the principal objectives of this study are as follows:

1. To identify and examine the various ferrous shredding operations in Ontario.

2. To identify the sources of contaminants in the shredder operation feedstream which may contribute hazardous properties to the waste stream.

3. To review options for proper management and disposal of shredder wastes.

1.4 REPORT ORGANIZATION

This report contains the following Chapters:

Chapter 1 - Introduction

This Chapter contains a brief description of the ferrous metal shredding industry and the existing problems with shredder wastes disposal. The study objectives are also included.

Chapter 2 - Study Methodology

The information retrieval methods, including literature search, telephone and on-site surveys and site program are described in this Chapter.

Chapter 3 - Description of the Ontario Ferrous Metal Shredding Industry

Pertinent information about each of the nine Ontario shredding facilities, and an overview of the industry are presented. In addition, the feedstream delivery infrastructure is reviewed.

Chapter 4 - Shredder Waste Contaminants

The results from the only comprehensive survey of the contaminants contained in the shredder fluff are reviewed with respect to Ontario hazardous waste criteria. Contaminants of concern are identified to assist in focusing the review of the feedstream materials.

Chapter 5 - Components of Feedstream

This section identifies the materials in the feedstream components, ie. automobiles and white goods.

Chapter 6 - Review of Waste Management Options

This Chapter summarizes the management options available to control the levels of hazardous contaminants in the shredder waste stream.

Chapter 7 - Review of Waste Disposal Options

This Chapter presents a review of the potential options identified for the disposal of the shredder fluff.

Chapter 8 - Summary of Findings

This Chapter presents a summary of all of the study findings.

Three appendices are included in the report. Appendix A contains the RFP. Appendix B contains more detailed descriptions of incineration technologies and a complete list of study references is included in Appendix C.

Chapter 2
STUDY METHODOLOGY

The study involved four (4) major components. These were:

- A survey of Ontario ferrous metal shredding facilities.
- An information search.
- A site survey and study.
- The identification of shredder fluff management options for Ontario facilities.

Each of these activities is discussed in the following sub-sections.

2.1 SURVEY OF ONTARIO FACILITIES

In order to obtain general information on the Ontario shredding industry, and the specifics of the existing fluff management and disposal practices, each of the eight operating shredding facilities was contacted.

Initially, CH2M HILL contacted a representative from each facility by phone. Information requested at this time included:

- A description of the shredding process, including equipment manufacturer, capacity and operation.
- Description of the feedstream components, and delivery infrastructure.
- Description of the feedstream quality control methods used, including tracking, inspection and policing programs.
- Historical, present and projected methods of waste disposal, and associated problems.
- Characteristics of shredder fluff, including volumes and components. If previous characterization studies were carried out, then the results were requested.

Subsequent to the telephone survey, site visits were conducted by a CH2M HILL staff member at a selected number of facilities. The purpose of the site visit was to see a number of different types of shredding operations, and to allow more detailed discussions of the waste management and disposal methods with facility operators.

Table 2.1 presents the telephone survey and site visit locations. All surveys took place in the period of July to November 1989.

Table 2.1
SUMMARY OF ONTARIO SHREDDING FACILITIES SURVEYED DURING STUDY

Facility	Telephone Survey	Site Visit
Industrial Metal Division, LASCO, Whitby	x	x
Triple M, Metal (1980) Inc. Brampton	x	x
Compressed Metals (1987) Ltd. Toronto	x	x
Bakermet Ltd., Ottawa	x	x
Lakehead Scrap Metal, Thunder Bay	x	x
I.W. & S. Ferrous Ltd. Hamilton	x	
Intermeteo Ltd., Metals Recycling Division, Hamilton	x	
Zalev Brothers Ltd., Windsor	x	

2.2 INFORMATION SEARCH

The information search was carried out to retrieve information on the following topics:

1. Characterization of the shredder waste stream, to identify the contaminants of concern.

2. Identification of the components of the feed stream, and the materials used in the manufacturing of these components.

3. Identification of the various options available for feedstream and waste management, to control the levels of contaminants in the shredder fluff.

4. Identification of shredder fluff disposal alternatives.

A number of sources were used to obtain the above information. These are described below.

Manufacturers

Manufacturers of the various feedstream components and of the materials used in specific components were contacted by telephone and mail in order to request information on the past, present and future uses of various materials in the manufacturing of their product.

Recycling Associations

The Canadian Association of Recycling Industries (CARI), the U.S. Institute of Scrap Recycling Industries (I.S.R.I.) and the European Bureau Internationale de la Recuperation (B.I.R.) were contacted. The purpose of this contact was to inquire about any non-traditional methods of shredder fluff management and disposal which are practised by their members. From this request, specific contacts at local or state governments and shredding facilities were identified.

U.S. Environmental Protection Agency (EPA)

The U.S. EPA was contacted to establish whether any studies of shredder waste had been or were being done in the U.S. Additionally, the U.S. EPA supplied additional information and names of people to contact regarding local shredder fluff management techniques used.

Ontario Ministry of the Environment (MOE)

Contacts with MOE staff, and various MOE documents were used throughout the study to obtain information on the existing legislation on waste management and disposal practices in Ontario.

Municipal Governments in Ontario

In order to establish current white goods disposal pathways in Ontario, a number of municipal governments were contacted.

Other Sources

A number of other potential information sources were identified during the information search. Whenever these were identified, they were contacted either by telephone or letter.

Literature Review

A major component of the information retrieval was the execution of an extensive literature review. Although some literature was obtained from other sources, the largest portion was identified using the CAN/OLE^{R} service of the Canadian Institute for Scientific and Technical Information. This service allows an on-line search of more than 25 computerized databases. The primary databases used in this study included:

1. The National Technical Information Service (NTIS), a catalogue of U.S. government-sponsored research, development and engineering reports (over 1.2 million references).

2. The Engineering Index (EI) and the Engineering Index-Meetings (EIM) produced by Engineering Information Inc., which cover all aspects of engineering and related technologies including over 2,000 technical conferences each year (over 2.3 million references).

3. The Materials Business File (MBF) produced by Materials Information (a joint service of the American Society for Metals and the Institute of Metals, London), which provides a comprehensive coverage of technical and commercial developments in the areas of iron and steel, (including over 19,200 references).

2.3 ON-SITE SURVEY

The information search revealed that only very limited information was available on the use of PCB containing capacitors in appliances. Furthermore, the feasibility of operating a capacitor removal program in Ontario was unknown. Since the County of Fairfax, in Virginia, had been operating a program of capacitor removal from white goods since 1988, a CH2M HILL staff member visited the County of Fairfax site.

The objectives of the site visit were:

1. To conduct a survey of the appliances being shredded over a 3 to 4 day period. for the purpose of establishing the types of appliances being shredded and the incidence of capacitors in various types of appliances.

2. To observe all aspects of the capacitor removal program.

3. To obtain information that might pertain to any aspect of the current study.

The appliance survey results are discussed in Chapter 3. The other observations from the Fairfax County visits are referred to throughout the report.

2.4 DEVELOPMENT OF WASTE MANAGEMENT OPTIONS

The Joint Technical Committee, providing direction to the study, included personnel from the MOE Waste Management Branch as well as representatives from the Canadian Associations of Recycling Industries. Once the majority of the information retrieval work was completed, this was summarized for the Joint Technical Committee (JTC).

At a meeting of the JTC in November 1989, the methods for management of the shredder feedstream to control contaminants in the waste stream, and methods for waste management were discussed. A number of waste disposal options were reviewed at this meeting, which are included in Chapter 7 of this report.

Chapter 3
OVERVIEW OF ONTARIO SHREDDING INDUSTRY

3.1 ONTARIO FACILITIES

In Ontario, there are eight operating ferrous metal shredding facilities. Table 3.1 presents the locations and general information about each facility.

The facilities range in processing capacities from about 50,000 to 360,000 tonnes per year of steel scrap output. Lakehead Steel in Thunder Bay is operated only six months per year. Intermetco and IW&S are operating only on an irregular basis. Triple M has just recently begun operating and is processing only small volumes to optimize their equipment settings. The remaining five facilities operate one, two or three shifts per day, all year round. A ninth facility owned by Triple M, located in Mississauga, shreds only steel scrap and therefore does not produce the typical shredder waste material under study.

All of the shredding facilities provide mechanical shredding of the feedstream components, and magnetic separation of the iron and steel scrap. Five of the operating shredders use air cyclone separation of the fluff, two use water separation and one uses a mechanical separation system.

The non-ferrous metal stream from each of the Ontario facilities is hauled off-site for separation of the metallic components.

3.2 FEEDSTREAM COMPONENTS

The feedstream components consist of automobiles and auto parts, white goods and other scrap metal.

The largest component of the entire feedstream to Ontario shredding facilities is automobiles and auto parts. At three facilities, this component makes up one hundred percent of the present feed stream. At three others, automobiles make up about 90 percent of the feedstream. In total, at present, about 580,000 tonnes of autos and auto parts are presently processed annually in Ontario producing 450,000 tonnes of steel scrap.

White goods include traditional household appliances such as refrigerators, ranges, washing machines, dryers, etc. as well as water heaters and non-white appliances (eg. air conditioners, microwave ovens, televisions, etc.). One facility processes a feedstream that is about 35 to 40 percent white goods. Another processes a feed stream

Table 3.1
SUMMARY OF FERROUS METAL SHREDDING FACILTIES IN ONTARIO

Facility and Location	Processing Capacity based on 24 h/d (t/yr)	Present Operation	Estimated Present Waste Production (t/yr)	Present Feedstream Components	Disposal Method	Comments
Compressed Metals Toronto	48,000	24 h/d 48,000 t/yr	10,000	35-40% White goods -30% Auto parts 30-35% Loose tin	Municipal landfill	
Bakermet Inc. Ottawa	280,000	9 h/d 78,000 t/yr	20,000	100 % Autombiles and auto parts	Regional landfill	
Industrial Metals Division, LASCO, Whitby	360,000 (24 h/d)	24 h/d 360,000 t/yr	72,000	100 % Automobiles	Dedicated landfill	
I.W.&S. Ferrous Ltd. Hamilton	50,000	16 h/d Irregular operation.	Very little	25 % White goods 75 % Auto Parts and sheet metal	Private landfill	Not in full operation. Trying to minimize fluff production at present.
Triple M Metals Brampton	240,000	Not yet operating.	Est. 50,000	90 % Automobiles 10 % Scrap metals	Store on-site for interim period.	Not yet in full operation. No current plans for disposal.
Lakehead Scrap Metal Thunder Bay	100,000*	12 h/d (May - Oct.) 50,000 t/yr	10,000	80-90 % Automobiles 3-5 % White goods 5-10 % other	Municipal landfill	They are trying to get landfill to use as cover material at no charge.
Zalev Brothers Ltd. Windsor	200,000	8 h/d 60,000	17,000	90 % Automobiles 10 % Auto parts/scrap	Municipal landfill	
Intermetco Ltd. Metal Recycling Division Hamilton	120,000	Irregular operation.	Very little	Miscellaneous steel (at present)	Private landfill	Not in full operation. Trying to minimize fluff production at present.

which is 25 percent white goods whilst a third facility processes a feedstream that is less than 5 percent. Approximately 26,000 tonnes per year of household appliances are presently processed in Ontario producing 22,000 tonnes of steel scrap.

Three of the six operating facilities do not accept white goods. One reason sited was the slightly higher copper contribution from appliances to the steel scrap which lowers the quality of the scrap. However, the main reason for refusing white goods is the general concern that appliances may contribute to PCB and/or cadmium contamination of the fluff. There is no evidence to support this concern. Since the relative percentage of discarded appliances to the tonnage of discarded automobiles is small (about 20 percent), shredders feedstreams are not affected enough to motivate the shredder to overcome the perceived problems associated with accepting white goods.

Most of the feedstreams to Ontario shredders consist of some portion of scrap material. In total, about 70,000 tonnes per year of miscellaneous scrap metal is processed in Ontario. This material is primarily industrial waste, such as discarded equipment, scrap sheet metal, culverts, etc. This portion of the feedstream varies from 0 to 30 percent, depending on the facility. There is generally very little non-ferrous waste associated with the processing of these items.

3.3 DELIVERY INFRASTRUCTURE

Automobiles, auto parts, white goods and other miscellaneous steel scrap arrives to the shredding facility through a variety of different pathways. Figure 3.1 presents the primary pathways used in Ontario.

3.3.1 Automobiles

For automobiles, recycling begins when the owner decides to discard the auto. The owner may have the car towed to the local garage, where he will receive a small sum (about $50.00). The garage owner will remove from the car useable or saleable items, such as batteries, tires, radios, etc. and then have the remainder towed to the wrecker. Some owners have the car towed directly to the wrecker. However, this may not be convenient since wreckers are usually located on the outskirts of cities.

The main function of the auto wrecker is to salvage useful parts from discarded automobiles. It is also usually the wrecker who removes the key recyclable items, including batteries, copper radiators and catalytic converters. These items are stockpiled and sold to non-ferrous metal dealers. He will also remove those items that are refused by the metal shredder, including gas tanks, tires, etc. After all valuable and necessary parts are removed, the remaining hulk will be sold to the shredder for scrap.

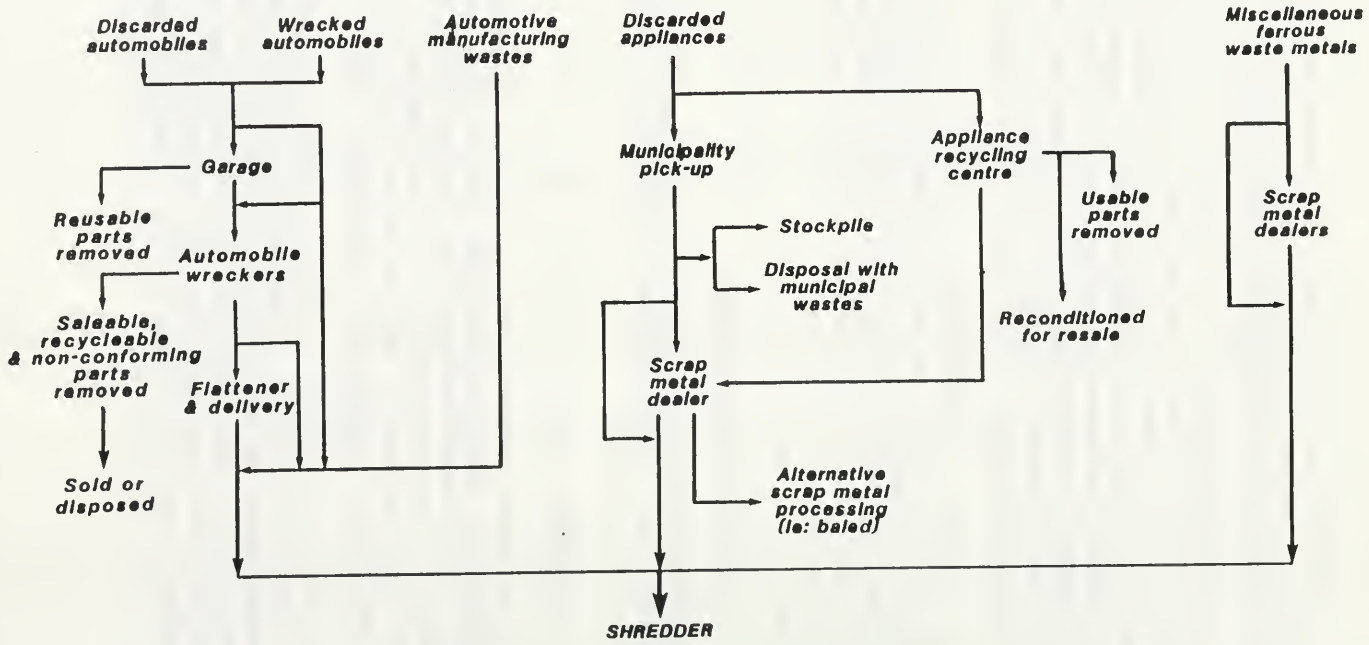

Figure 3.1

SCHEMATIC DELIVERY INFRASTRUCTURE OF FEEDSTREAM MATERIALS TO SHREDDING FACILITIES

In Ontario, the hulks may be delivered directly to the shredder. However, more often, hulks are compressed to a height of about 25 cm in a portable flattener and piled onto a flat bed semi-trailer for delivery. The flattener and trailer may be owned by a private contractor or the shredding facility receiving the hulks.

Occasionally, automobiles are brought directly to the shredder site, by-passing the garage, wrecker and flattening operations. This is only common in Thunder Bay, where the shredder operation is relatively small and within the city. Generally, the shredders purchase their automobiles from a variety of regular suppliers (wreckers).

Miscellaneous autoparts and autobodies may also be supplied from wreckers. For example, some shredders will accept a load of gas tanks that have been removed from the autos, drained of gasoline and split to release gases. Another supplier of parts and bodies are the auto manufacturers. Imperfect body pieces and parts are sold to the shredder as scrap.

White Goods

In Ontario, white goods discarded by the owner may be left for curbside pick-up or recycled through a used appliance service centre.

Curbside pick-up of appliances from residences is the responsibility of the individual municipality. In many areas, the municipality owns the vehicles. In other cases, curbside pick-up of appliances, as well as municipal waste, is performed by a contractor hired by the municipality. In municipalities where recycling of white goods is not practised, discarded appliances may be picked up and landfilled with municipal wastes, or stockpiled separately.

Where white goods recycling is practised, the appliances may be hauled directly to the shredder from the curbside or to an intermediate scrap metal dealer, who will then sell the goods to the shredder for scrap.

A number of used appliance service centres may also discard waste appliances. At these businesses, the appliance received from the original owner may be reconditioned and sold, but will more likely be stripped of usable parts and then discarded. When a sufficient volume of discarded white goods is accumulated, a scrap metal dealer is contracted to haul the goods away for disposal. The contractor may sell these goods to the shredder or to another metal recycling operation (eg. baler).

At appliance manufacturers, the small volume of waste metal components are stockpiled and then sold to a scrap metal dealer.

3.3.2 Miscellaneous Wastes

A number of industries in Ontario produce relatively small amounts of waste ferrous metal products. These may include, but are not limited to, the following:

- Construction materials such as steel siding, culverts, scrap sheet steel. pipes, etc.
- Industrial materials such as discarded equipment, scrap sheet steel, etc.
- Miscellaneous transportation materials including railway tracks, larger vehicles (train cars, buses, etc.).

Transformers and other electrical equipment are not accepted by Ontario shredders.

Miscellaneous steel wastes are sold to either the scrap metal dealer or directly to the shredder. These wastes may also be processed through other metal recycling operations such as baling.

3.4 FEEDSTREAM QUALITY CONTROL

Feedstream components, particularly automobiles, contain certain materials, the presence of which is undesirable to the shredder for a variety of reasons. Incoming loads are inspected to identify undesirable, or "non-conforming", items prior to shredding. The degree of inspection varies between the Ontario facilities.

The primary purposes of feedstream inspections are:

- To prevent materials from entering the shredder which can potentially damage the equipment, or pose a health or safety risk to shredder employees.
- To identify materials that increase the load weight (ie. "hidden" non-ferrous items) but do not contribute to the ferrous scrap output.
- To prevent materials of potentially contaminating nature from entering the waste stream.

Non-conforming materials may include the following:

- Materials which can cause explosions within the shredder, such as gas tanks, unspent sodium azide gas canisters, portable fire extinguishers, propane fuel tanks, etc. Most facilities in Ontario require that gas tanks be removed completely. One shredder, that uses water separation, does

not require removal of gas tanks as long as they are split prior to processing. This facility will also process a stockpile of gas tanks as long as they have been drained of gasoline and split to release gases. Most facilities will not accept gas tanks, and these are usually recycled in a baling operation.

- Tires, since they do not contribute to the steel output but increase the waste volume.

- Batteries, because they can contribute to the lead levels in the waste stream. As noted, the garage supplier usually manually removes batteries to sell separately.

- Containers, such as closed steel drums, paint cans and electrical transformers that may contain hazardous wastes, such as paint, solvents, PCBs, etc. Also, asbestos wastes, and mercury-containing wastes are non-conforming.

- Radioactive materials. Most Ontario shredders have radiation detection systems in place to check radioactivity of incoming loads.

- Other obviously hazardous materials.

The quality control inspection procedures generally take place at two levels; with the supplier and on-site.

The shredder specifies to the supplier a list of non-conforming items. The shredders' requirements may be documented in a very detailed manner or simply expressed verbally. At one facility in Ontario, a detailed quality assurance program is being developed, whereby a comprehensive record of the performance of a supplier will be kept and notices will be issued when non-conforming items enter the feedstream. At most facilities, the shredder's requirements are expressed less stringently, and depend on good business relations.

The reaction of the shredder to non-conforming items identified in a load depends on the nature of the items. Where gas or propane tanks are overlooked by inspection and go through the shredder, there may be a weight deduction to the supplier responsible, to pay for the equipment maintenance required after any explosion. If non-conforming items are detected by the inspector during unloading, the entire load could be refused.

The on-site quality control program at each facility involves inspection of the incoming loads at least once before the items enter the shredder. Generally, the items are inspected visually during unloading, and colour coded to identify the supplier. At most sites, the items are again visually inspected as they are being lifted by crane toward the

shredder. The crane operator provides an additional inspection, since he can identify items that are unusually heavy or unbalanced and possibly containing non-conforming items.

Spot checks are generally carried out when a feedstream component is suspect. This will involve removing the item, usually an automobile, and opening it up for examination.

The inspection programs at Ontario facilities are for the most part successful in identifying non-conforming items prior to the component entering the shredder. However, occasional explosions in the shredders indicate that complete detection and elimination of these items is not possible.

3.5 WASTE DISPOSAL

In total, from all operating Ontario ferrous metal shredding facilities, approximately 140,000 tonnes of shredder fluff requires disposal each year. Based on an approximate density of 320 kg/m^3 (Wolman, et. al. 1986), this is equivalent to about 440,000 m^3 of waste.

Disposal by landfilling with municipal waste has been and is presently (with one exception) the only method of disposal in Ontario. At the Ottawa, Thunder Bay and Windsor facilities, landfilling is expected to be the method to be used in the foreseeable future. Up until 1988, Bakermet in Ottawa did not pay disposal costs to the Regional landfill since the landfill used the fluff as cover material. At Lakehead Steel, in Thunder Bay, the shredder is attempting to convince the municipal landfill operator to use the fluff as cover material, thereby eliminating disposal costs.

At one facility, disposal in an experimental dedicated landfill is presently under going an Environmental Assessment, under the Environmental Assessment Act (1989). The landfill, in the form of a berm which surrounds the property, is discussed in greater detail in Chapter 7. The primary reason for developing the berm as an alternative to landfill disposal was the difficulty in locating sites within an economic haul distance which could accept the material. In addition, local landfills are nearing capacity and would likely close within five years. As a result, a development of a long term waste management strategy was deemed necessary.

With the exception of the facility in Thunder Bay, the primary concern of the shredders is the rapidly increasing cost of landfilling their wastes, as discussed in Section 1.2.

There are two operating shredding facilities in Hamilton, Ontario. Samples of shearer wastes and shredder fluff (possibly containing PCB contaminated soil) from a third facility in Hamilton, which has since shut-down, showed levels of PCB higher than those

permitted under Reg. 309 for disposal as a non-hazardous waste. Thus, the local landfill banned fluff from all of the Hamilton shredders from their facility. Before the matter was resolved, the landfill reached certified capacity. As a result, the shredding facilities, together with a few other scrap metal processors, began to investigate other alternatives for disposal of their wastes. At present, the shredders are operating intermittently and only shredding items that produce minimal wastes.

The Regional Municipality of Hamilton-Wentworth conducted a number of tests for incinerating the fluff at the municipal incinerator, SWARU. A total of about 500 tonnes of the waste were incinerated at SWARU. The results indicated that incineration was a feasible alternative. However, modifications to the existing facility may be necessary for handling of the shredder fluff.

At the time of this report, the shredders had not come to an agreement with the Region about incineration of the fluff. The shredders are presently having fluff hauled to a private landfill, at a relatively high cost. Therefore, operation is only intermittent, to reduce fluff volumes and disposal costs.

Chapter 4
SHREDDER WASTE CONTAMINANTS

A review of the various studies carried out to characterize shredder fluff was conducted as part of this study. Components which could cause fluff to be characterized as a hazardous waste under Ontario Regulation 309 were identified. Identifying which components were at levels of concern helped to focus the investigation to characterize feedstream materials. This component of the study is discussed in detail in Chapter 5.

Solid wastes are designated as registerable if the leachate contains contaminants listed in Schedule 4 of Reg. 309 in concentrations between 10 and 100 times the concentration listed. Wastes are hazardous and also would require registration if any concentration exceeds 100 times the concentration listed. Table 4.1 presents the Schedule 4 concentrations for suspected contaminants of concern in shredder fluff. In addition, waste containing more that 50 mg/kg of total PCB is considered hazardous (PCB wastes as defined in Regulation 11/82).

Table 4.1
ONTARIO REGULATION 309 SCHEDULE 4
LEACHATE QUALITY CRITERIA

Contaminant	Concentration (mg/L)
Arsenic	0.05
Barium	1.0
Boron	5.0
Cadmium	0.005
Chromium	0.05
Fluoride	2.4
Lead	0.05
PCB	0.003

In 1980, an industry-wide survey was conducted by Clayton Environmental Consultants, Inc. for the Institute of Scrap Iron and Steel (I.S.I.S.), Inc. (now called the Institute of Scrap Recycling Industries, I.S.R.I.). The purpose of the survey was to characterize the contaminants leached from wastes produced in a number of processes in the ferrous scrap industry (Clayton, 1980). This study provides to date the most comprehensive database on fluff leachate contaminants. However, there is one main limitation of

applying the 10 year old study results to today's situation. That is that automobiles and appliances shredded at that time were likely composed of different materials in different proportions than those being discarded today.

A statistically developed sampling strategy was used in the Clayton study, which allowed a 95 percent confidence of representing the sample population. Fluff from 40 different shredder sites was sampled, and 13 of these sites were sampled 3 additional times to establish whether there was a significant in-site variation. This study did not distinguish between shredders using different feed stream materials. Shredders involved had typical feedstream materials that included automobiles, white goods, scrap steel, etc.

Table 4.2 lists the parameters analyzed in the sample leachate. All of the samples were extracted using U.S. EPA stirrer method defined in Document No. SW-846 (U.S. EPA, 1980). This method is no longer used because it did not produce sufficient mixing and was found to grind particles during mixing. Therefore, the results produced are not directly comparable to the Reg. 309 method used in Ontario, which uses tumbler mixing. There is however, no evidence to suggest that one method produces consistently higher or lower results than the other. The results of this study are presented because no other data are available.

The results indicated that the sampling method was valid as there was no significant difference in results from the within-site and between-site samples.

With the exception of barium, cadmium and lead, all of the contaminants analyzed in the Clayton Study were below the detection limits in every sample. The data for these parameters were plotted by CH2M HILL on log-normal probability paper to show that the data follows this type of probability distribution. The geometric mean and 90 percentile concentration of the data for barium, cadmium and lead were computed. These values are compared in Table 4.3 to the Reg. 309 criteria.

What is most interesting is the relative homogeneity of the data. The 90 percentile values for each of these parameters are less than one order of magnitude higher than the median value. Cadmium is the most homogeneous compound, as indicated by a spread factor of less than two. For all three contaminants of concern, the mean concentrations were less than the Reg. 309 hazardous waste levels. The sampling results show that cadmium levels were less than the Schedule 4 hazardous waste levels in 60 percent of samples. For lead, 81 percent of samples had levels less than the criteria. For barium, greater than 99 percent of the samples had concentrations less than the criteria.

Table 4.2
PARAMETERS ANALYZED IN LEACHATE
EXTRACTED FROM SHREDDER FLUFF SAMPLES
(Clayton, 1980)

Contaminant	Method Detection Limit (MDL) (mg/L)
Arsenic	0.01
Barium	0.3
Cadmium	0.02
Chromium	0.3
Lead	0.3
Mercury	0.01
Selenium	0.01
Silver	0.05
Endrin	0.002
Lindane	4.04
Methoxchlor	1.0
Toxaphene	0.05
2,4-Dichlorophenoxayacetic	10
2,4,5-TP (Silvex)	1

Table 4.3
CONCENTRATIONS OF CONTAMINANTS IN LEACHATE
EXTRACTED FROM SHREDDER FLUFF SAMPLES[1]

Contaminant	Geometric Mean	Spread Factor	90 Percentile Conc.	Percent Less Than Hazardous Waste Level	Reg. 309 Hazardous Waste Conc.
Cadmium (mg/L)	0.44	1.59	0.84	59.4%	0.5
Lead (mg/L)	2.3	3.32	7.3	80.8%	5.0
Barium (mg/L)	7.5	3.6	28.4	99.4%	100.0

[1]Based on results presented in Clayton report (1980).

Fluff leachate extraction and analyses are not carried out routinely at Ontario facilities. In the past, a limited number of characterizations were performed. These data are compared to the Clayton results in Table 4.4. Since these data are based on one grab sample from each facility there is no statistical significance to these results. Furthermore, inter-laboratory variability in these types of analyses are common, as a result of different sample handling techniques, sample preservation, and differences in analytical methods. In addition, there is room for a large variability even within the Reg. 309 leachate extraction procedure. However, the results were included for the purpose of completeness.

Table 4.4
LEACHATE EXTRACTION AND ANALYSES
PERFORMED ON SHREDDER FLUFF FROM ONTARIO FACILITIES

Regulation 309 Parameter	Clayton 90 Percentile	Bakermet[1]	Compressed Metals[2]	Hazardous Conc.
Arsenic	< 0.01	< 0.05	-	5.0
Barium	28.4	1.91	-	100.0
Cadmium	0.84	0.003	0.86	0.50
Chromium	< 0.3	< 0.05	-	5.0
Lead	7.31	4.68	0.49	5.0
Mercury	< 0.01	< 0.0002	-	0.1
Selenium	< 0.01	< 0.05	-	1.0
Silver	< 0.05	< 0.0001	-	5.0
Nitrates	-	5.1	-	1000.0
Oil & Grease	-	3.0	-	-
PCB	-	< 0.01	-	0.30
Fluoride	-	0.24	-	240.0

[1]ECO - Research, 1988.
[2]SENES Consultants, 1988.

Bulk analysis of a single, non-statistically representative grab sample of shredder fluff from one Ontario facility showed 35 mg/kg of PCB. Furthermore, recent tests of fluff from Orange County, California, Iowa, Rhode Island, and Massachusetts showed PCB

concentrations in some samples greater than the regulatory limit (50 mg/kg) (Apotheker, 1989). The U.S. EPA is presently undertaking a study to statistically establish levels of PCB as well as lead and cadmium, in shredder fluff. As part of this investigation, a pilot study is being conducted to establish PCB, lead and cadmium levels in fluff from seven shredders in the United States. Study results are expected to be available in late 1990 (U.S. EPA, 1990).

In summary, the mean concentration of lead, cadmium and possibly barium were lower than the Reg. 309 hazardous waste criteria in leachate extracted from shredder fluff samples from wastes shredded in 1980. The leachate procedure used is somewhat different to the Regulation 309 procedure, but the 1980 study provides the only data available for discussion at this time. Levels of lead and cadmium did exceed the criteria in some samples. Furthermore, there is more recent evidence that PCB levels in fluff may be high enough in some fluff samples to define this waste as hazardous. However, because there has not been statistically representative sampling and analysis of the homogenous material for PCBs, there is no evidence that the actual PCB content of shredder fluff is high enough to result in hazardous waste designation.

Chapter 5
COMPONENTS OF FEEDSTREAMS

5.1 AUTOMOBILES

In 1990, approximately 800,000 automobiles will be discarded in Canada, and 350,000 in Ontario. This will generate 450,000 tonnes of scrap steel from automobiles in Ontario (based on projections presented by Mahoney et. al., 1979). The average age of a discarded vehicle is 8.5 years, and more than 80 percent of cars are junked after 5 to 14 years (Kaiser et. al., 1977). Thus, most of the cars being shredded today were manufactured between 1976 and 1985.

Automobiles are probably the most prominent consumer product in our society today. They are also undergoing a rapid change in composition. Ferrous metal content has and will continue to drop while both non-ferrous metal and plastic content will both increase. This is likely to have significant impact on metal shredders in the future. It is estimated that material changes will become evident in the recycling system approximately ten years after they take place in the manufacturing phase.

Table 5.1 presents a comparison of U.S. automobiles manufactured in the mid-1970s to Japanese and U.S. automobiles manufactured in the early and mid-1980s. Generally, the overall weight of the automobile has declined due primarily to the reduction in the ferrous portion of the automobile. In the mid 1970s, mid-sized automobiles were in the 1,600 to 1,700 kg range and contained about 1,400 kg of steel. In 1980 cars, the steel content was about 900 to 1,400 kg. Today a marked reduction in the vehicle's weight has been achieved through the increased use of plastics and composites and an overall reduction in the size of the average automobile. This trend is expected to continue.

5.1.1 Iron and Steel

A number of studies have been carried out on shredder product and residues. Typically, the magnetic portion accounts for approximately 70 to 80 percent of the automobile's weight. Late model automobiles tend to be in the lower end of this range. Sterner et al. (1984) estimated the magnetic portion of a typical 1981 Japanese automobile at approximately 75 percent. Mahoney et al. (1979) estimated the magnetic portion of junk automobiles in general at 76 percent for the year 1979. However, he had projected this percentage to drop to 69 percent by 1995.

Table 5.2 presents the various types of ferrous products used in automobiles. As shown, the general trend is toward reducing the use of heavier steel and iron components. The proportion of light steel has increased. However, taking into account the reduced total weight of cars, there has also been an overall reduction in the use of light steel as well.

Table 5.1
COMPARISON OF MATERIALS DISTRIBUTION IN
1970s AND 1980s AUTOMOBILES

Material	1970s U.S. Automobiles(1)		1980s Japanese Automobiles(2)		1980 Ford Automobile(4)		1985 Ford Automobile(4)	
	(kg)	(%)	(kg)	(%)	(kg)	(%)	(kg)	(%)
Total Weight	1,751	100	880	100	1,410	100	1,272	100
Total Ferrous Metals	1,438	82	670	76	1,064	76	932	73
Aluminum	37	2.2	39	4.4	61	3.6	74	5.3
Copper	22	1.2	10	1.3	14	1.0	11	0.9
Lead	(3)0.4	0.0	(3)0.4	0.0	13	0.9	13	1.0
Zinc	20	1.1	2.4	0.3	7	0.5	5	0.4
Total Non-Ferrous Metals	79	4.6	52	6.0	95	6.0	103	7.6
Glass	43	2.4	31	3.5	40	2.8	33	2.6
Other Non-Combustibles	10	0.5	2	0.2	-	-	-	-
Total Non-Combustibles	44	2.9	33	3.7	40	2.8	33	2.6
Plastics	59	3.3	51	5.8	99	7.0	108	8.5
Rubber	82	4.8	53	6.0	68	4.8	57	4.5
Other Combustibles	49	2.8	21	2.4	44	3.1	45	3.5
Total Combustibles	190	10.9	125	14.2	211	14.9	210	16.5

(1) Average for 5 U.S. automobiles, including: 1972 Mercury Montego, 1973 Ford Mustang, 1975 Ford Pinto, 1975 Cheverolet Caprice and 1976 Cadillac Seville (Dean et. al., 1985)

(2) Average for four hand dismantled Japanese automobiles, including: 1981 Honda Accord, 1981 Toyota Tercel, 1981 Datsun 210 and 1982 Nissan Sentra (Sterner et. al., 1984)

(3) Excluding battery

(4) From Ford Motor Co. (Phoenix Quarterly, Spring 1987)

Table 5.2
FERROUS METALS USED IN AUTOMOBILES
(Sterner et. al., 1984)

Material	% of Total Steel 1960s	1970s	1980s	Uses
Cast Iron	14.5	9.8	6.3	Engine [1,2] Carburetor [1] Distributor [1,2] Brake Drums and Cylinders [1,2] Steering Gearbox [1,2]
Light Steel (<3 mm thick)	36.5	43.1	48.1	Radiator Electric Motors [2] Radio Interior Trim Horn and Relay Window Frames Body Trim Body and Light Spring Steel
Heavy Steel (>3 mm thick)	34.2	28.5	21.1	Differential [1,3] Starter and Solenoid [1] Generator [1] Transmission [1,3] Wheel Covers and Wheels [1] Springs, Suspensions, Heels, Gears, Palls, Oil Pump and Frame
Stainless Steel	0.1	0.2	0.6	No Data

[1]Also contains light steel.
[2]Also contains heavy steel.
[3]Also contains cast iron.

Less than 15 percent of the automobiles weight is cast iron, the majority of which is contained in the car's engine. A small amount can also be found in the differential. brake drums and cylinders.

Heavy steel or iron is found mostly in the springs, suspension, hubs, gears and frame. etc.. It also makes up a major proportion of the transmission and differential and to a lesser extent is also found in the engine. Some wheels and wheel covers of many earlier models were, for the most part, made of heavy steel. Today aluminum is becoming more popular for use in wheels and wheel covers.

Light iron or steel is found much more extensively throughout the automobile. Just about every part or component contains some amount of steel. The body of the automobile contains up to 85 percent of the steel.

The recovery of the ferrous metals from automobiles is dependent on the effectiveness of the shredding and separation processes. Reports have shown that proportions of 10 to 22 percent of the fluff is ferrous metal, or 2 to 4 percent of the original iron and steel content of the car (Bibrey et. al., 1979). More modern shredding operations can expect much better ferrous metal recovery, accounting for less than 5 percent of residue (Wesolowski, 1990). Thus, it can be shown that 96 to greater than 99 percent of the original ferrous content of automobiles is recovered as steel scrap in the shredding process.

5.1.2 Non-Magnetic Metals

In the mid 1970's, the non-magnetic metal portion constituted approximately 5 percent of the vehicles weight. Today, the non-ferrous metal may be 6 to 7 percent of the vehicles weight. This is due to both increased use of aluminum and the decrease in the overall weight of the automobiles. Table 5.3 presents the main uses of non-ferrous metals in components of automobiles.

In earlier models, aluminum was found mostly in the engine and transmission. Today some engine blocks are made almost entirely of aluminum. Although engine blocks are removed from some discarded automobiles, parts of concern to shredders include tubing, electrical motors within the automobile and interior and exterior trim. Due to the lightness and strength of aluminum, its use as an alternative to light and heavy steel for many body parts is increasing. This trend is expected to continue.

The use of copper and zinc is expected to decrease in coming years (Berger, 1989). Copper is found mostly in the radiator and wiring within the automobile. Copper wiring attached to steel components pose potential problems to shredders, since the copper often ends up in the ferrous scrap. The quality of the scrap may be deleteriously affected by a high copper content.

Table 5.3
NON-FERROUS METAL USED IN AUTOMOBILES
(Dean et. al., 1985)

Material	% of Total Weight of Automobiles			Uses
	1960s	1970s	1980s	
Aluminum	1.4	2.1	4.4	Engine Fly Wheel Housing Generator Electric Motors Interior Trim Exterior Trim Transmission
Copper	0.9	1.3	1.3	Battery Cable and Clamps Radiator Starter and Solenoid Generator Heater Core Body Wiring
Zinc	1.5	1.1	0.3	Fuel Pumps Carburetor Electric Motors Instruments Radio Interior Trim Mirrors Interior, Exterior Handles Window Frames Body Coatings

Zinc was used extensively in earlier models on interior trim items. There has been a significant reduction in the use of zinc for auto parts over the past 30 years.

Virtually all of the non-ferrous metal components are separated into the non-ferrous metal stream during the shredding process. However, traces of these non-ferrous metals, accounting for up to 2 percent end up in the fluff stream (Valdez, 1976). Experience at one Ontario shredding facility shows that this is typically less than one percent (Wesolowski, 1990).

5.1.3 Lead

Although lead is not used as extensively as the other non-ferrous metals discussed in the manufacturing of automobiles, its presence presents the most concern to the shredder in terms of potential for contamination of the shredder fluff. Furthermore, in addition to the use of lead in manufacturing, lead may accumulate in certain components of the automobile with use, as a result of leaded gasolines.

Manufactured components that are the primary sources of lead in automobiles are:

- Batteries
- Battery cable clamps
- Lead wheel weights
- Coatings and fillers

Up to 8 kg of lead is recoverable from batteries and 0.2 kg from battery cable clamps (Dean et. al., 1985). In addition, up to 0.3 kg of lead per vehicle may be used for wheel weights. However, these generally do not pose a concern since wheels are usually removed at the wrecker.

In general, batteries and battery cable clamps are removed by the wrecker and sold separately for the lead. However, the demand for lead batteries is dependant on the market. In the past, during periods when lead value was low, batteries may not have been removed from every vehicle. At present, with the concern over lead contamination of the waste stream, shredders require that all lead batteries be removed from automobiles prior to processing.

Lead was also used historically in various automobile coatings and fillers. This is discussed in greater detail in Section 5.1.5.

The use of leaded gasoline in an automobile results in the deposition of lead oxides in the engine and exhaust system. The introduction of catalytic converters as pollution control devices in the 1970s resulted in the limited use of unleaded fuels. Unleaded fuels were required since lead contaminates the platinum catalyst used to reduce carbon monoxide emissions from a vehicle by adhering to the platinum surface inside the catalytic converter. As the number of vehicles with catalytic converters increased so did

the use of unleaded fuels. However in the mid-1980s, due to the price difference between leaded and unleaded gasoline there was an increase in the production of vehicles which could burn the cheaper leaded fuel and still meet carbon monoxide emission requirements.

Recently the Canadian Government has banned the use of leaded fuels in all automobiles beginning in 1990. This will eliminate exhaust systems as a source of lead oxide by approximately the year 2000. In the meantime a significant number of automobiles which are shredded have the potential for lead contamination of the residue through flaking of the lead oxides from the interior of the exhaust system during the shredding process. Those vehicles with catalytic converters should have exhaust systems which are relatively free of lead deposits.

5.1.4 Organic Polymer Materials

Organic polymeric materials used in auto manufacturing include a wide range of plastics, fibres and rubber. The use of these materials has risen significantly over the last two or three decades (Chemical Week, February 20, 1988; Phoenix Quarterly, Spring 1987). The current trend indicates that the available plastics and rubber content from a discarded automobile will increase at a rate of about 4 percent per year (Mahoney et. al., 1979). Vehicles presently being shredded, from the early 1980s, contain an average of 100 kg of plastics and fibrous materials (Curlee, 1985).

The increased use of plastics is attributed to the lighter weight of these materials compared to metal components. The use of these materials is likely to continue to increase as more applications are discovered where they provide the necessary strength at a fraction of the weight. Consequently, the amount of plastic in the residue as a proportion of the magnetic product is increasing.

Organic polymeric materials used in auto manufacturing fall into the following three categories (Kinstle, 1984):

- Thermoplastics - A single polymer that flows when heated.
- Thermosets - A cross-linked polymer which cannot be dissolved or thermally processed.
- Composites - Thermoplastics and thermosets which contain other agents or additives to provide a desirable characteristic.

Thermoplastic components of automobiles include tires, battery case, ducts, interior panels (door, roof) etc. Thermoset components include hoses and belts, engine suspension mounts, foam linings (polyethylene) and some molded items. Examples of composite materials include glass reinforced plastics and fibre reinforced plastics.

The breakdown of plastics excluding rubber in 1960s and 1970s automobiles is shown in Table 5.4. The purposes of this presentation are to illustrate both the increase in the variety, as well as the weight of organic polymeric materials used in automobiles.

Table 5.4
PLASTICS COMPOSITION IN AUTOMOBILES
(Dean et. al., 1985)

	1960s[1]		1970s[1]	
Plastics	(kg)	(%)	(kg)	(%)
Polypropylene	2.3	19.6	14.0	29.7
Vinyl	9.0	76.5	10.1	21.1
Polyurethane Foam	-	-	8.2	17.1
Nylon	-	-	6.5	13.6
Acrylonitrile - butadiene - styrene (ABS)	-	-	4.7	9.7
Polythylene	-	-	2.1	4.4
Acrylic	0.3	2.7	1.6	3.3
Bakelite	0.1	1.2	0.9	1.8
Thermosetting	-	-	0.14	0.3
Total	11.7	100	48.1	100

[1]Circa 1960 automobile.
[2]Average for 1972 Mercury Montego and 1973 Mustang Mach I.

One of the chief ingredients of the lighter fraction separated at shredding facilities is polyurethane foam, which is one of the main components of seats and padding throughout the vehicle. Other components in the plastics include polypropylene, ABS plastics and glass fibre reinforced polyester thermoset. As well, increased use of reinforced composites for structural applications will further complicate the mix (Harwood, 1977) of plastics found in an automobile.

Although lead and cadmium are used in plastics (eg. PVC stabilizers) these are bound in the plastic (Henstock, 1984). Therefore, the plastic material is reported to be more or less inert when undergoing a Reg. 309 leachate extraction and therefore contributes little in the way of hazardous components to the fluff leachate.

5.1.5 Paints, Coatings and Fillers

Paints and coatings used on the automobile may be another possible source of hazardous material in shredder residue. Paints and coatings as well as body fillers on earlier models may have contained various levels of lead and/or cadmium (Ness, 1984). The recognition of the hazards of these materials has caused many firms to discontinue manufacturing materials containing these metals. Although some paint manufacturers produced paints for various applications which contain PCBs prior to 1972, these PCB containing paints were not used on automobiles.

Today's automobiles may contain as many as eight different layers of coatings. Table 5.5 lists the coatings found on an automobile.

Table 5.5
AUTOMOBILE COATINGS

1) Primer Surfacer
2) Primer (electrolytic deposition)
3) Anti-chip Coating
4) Basecoat
5) Colour Coat
6) Lacquer
7) Neo Amilac Coat
8) Clearcoat

Automobile coatings contain ingredients from four basic categories; carrier, binding agent, pigment and additives. The carrier is the liquid phase of the paint and could be anything from water to complex solvents. The binding agent is either a latex or polymer and the pigment provides the colour and some protection. Most paints usually contain additives such as dryers, UV screens, flotation agents, etc. Colour in the paint is provided by compounds such as titanium dioxide, carbon black, barium sulphate, iron oxide and various pigments.

In the past, cadmium was a major component of yellow pigments and a number of other coatings. The recognition of the toxicity of cadmium has resulted in the development and use of alternatives such as tetrachloroisolinore yellow pigment. For the past ten years cadmium has not been used in automotive paint coatings. This information was verified by several car manufacturers in Ontario, and C-I-L Paints, a major producer of automotive paints (Custom Paint Supply, 1990; CAMI, 1990; C-I-L, 1990).

Automobiles currently being shredded were manufactured 10 years previously. The coatings on vehicles manufacturer prior to 1980 did contain various levels of cadmium which probably explains the relatively homogeneous levels of cadmium found in 1980s shredder fluff (Clayton, 1980). An effort was made during this study to determine when the use of cadmium as a paint pigment ceased. However, all efforts to obtain this information were unsuccessful. It is anticipated that cadmium levels will slowly drop as vehicles which do not contain cadmium in their coatings are discarded.

Lead containing compounds have been used extensively in many of the automobile primer coatings and in automotive paints pigments. Lead compounds have been eliminated from most coatings. However, lead chromate is still being used in the production of automotive paints, although companies like C-I-L Paints have been progressing towards lead-free paints in the past 10 years (C-I-L, 1990). Dupont ceased using lead in their coatings in 1980. The concentration of the lead in the paints vary, but the paints with the highest concentrations of lead in them are the yellow and orange paints. The concentration of lead (compounds) varies from 5 to 60 percent in the tinting base that is used to add pigment to these paints. Vehicles painted with "fleet-colours" and trucks will contain the highest amounts of lead (C-I-L, 1990), and since lead compounds make up 0.07% of some precoats (CAMI, 1990), there is no guarantee that any car on the road has completely lead-free coatings.

In older automobiles, appreciable quantities of lead were used in seam and body filler to repair cars. Lead is not presently being used for this purpose (CAMI, 1990). It is unknown when the use of lead for this purpose ceased.

5.1.6 Other Components

Other components of the automobile have the potential for contaminating the shredder residue. At present, quality control procedures used by most shredders prevent a majority of these materials from entering the shredder. For example, the removal of lead-acid batteries and wheels (which may contain lead wheel weights) helps to prevent lead from entering the shredder. Batteries are recycled through a well established secondary lead smelting industry.

Some catalytic converters may also contain lead if the owner had used a significant amount of leaded gasoline. In this situation, the platinum catalyst in the catalytic converter may be contaminated with lead. However, the value of the platinum catalyst in the converter provides a strong incentive for its removal.

Most of the components that have been discussed focus on the issue of lead. Since lead has a high specific gravity, the tendency for contamination of the shredder fluff may be low as it is easily separated by either air or water classification. Even lead oxides have a relatively high specific gravity and should be easily removed.

Another concern that has come to the attention of the shredding industry is sodium azide air canisters in cars (Phoenix Quarterly, Summer 1978) Pressurized canisters of sodium azide, contained in cars, are designed to inflate a bag upon impact, therefore cushioning the driver and passenger in the front seat in an accident. Unspent sodium azide canisters pose two main concerns to shredders. The first is that the U.S. National Institute of Occupational Safety and Health (NIOSH) classifies sodium azide as a "suspected mutenogenic", and that one part per million in air has produced a toxic response in test animals. For the shredder, processing 150 to 800 cars daily, there is a concern with the accumulation of this chemical in machinery crevices, coolant water and fluff. The U.S. National Highway Traffic Safety Administration (NHTSA) have argued that the chemical decomposes quickly and therefore should not pose any serious health or environmental problems.

Secondly, sodium azide is highly explosive. Thus, there is a concern regarding the potential for explosion or fires during the shredding process. Removal of the canisters prior to shredding would eliminate these concerns.

5.1.7 Summary

Approximately 580,000 tonnes of automobiles are discarded each year in Ontario. About 75 percent of this weight, or 450,000 tonnes, is recoverable steel. However, the trend has been toward decreasing the steel content of cars. Thus, the shredder fluff stream will continue to be a larger portion of the total volume processed.

Non-magnetic metals, primarily aluminum, copper and zinc, account for about 5 percent of the vehicles weight. The use of zinc has decreased over time, while aluminum use has increased.

Lead is present in batteries, battery cable clamps, lead wheel weights and coatings and fillers of older cars. Lead is no longer being used in most coatings and fillers, however is still used to a decreasing extent in some paint pigments. Also, lead deposits are present in the exhaust trains of vehicles which used leaded gasoline.

The organic polymeric materials content of automobiles has risen in the last two decades as the steel content has decreased. Approximately 100 kg of the vehicles weight is attributed to plastics in the 1980s. A broad range of types of organic materials are present in automobiles.

Sodium azide air bag canisters used in new cars may pose a problem in automobile shredding due to the toxicity of this chemical and its explosive nature.

5.2 WHITE GOODS

Table 5.6 presents a list of items found in white goods disposal streams. It is estimated that the overall tonnage of white goods available for recycling in Ontario in 1989 is 95,000 tonnes based on per capita rates of appliances being discarded in the U.S. in 1988 (Apotheker, 1989).

Table 5.6
ITEMS IN WHITE GOODS DISPOSAL STREAMS

Primary:	Refrigerators
	Freezers
	Stoves (ranges)
	Dishwashers
	Washers
	Dryers
	Water Heaters
	Room Air Conditioners
	Furnaces
Non-typical:	Microwave Ovens
	Photocopiers
	Televisions

There is little information available on the composition of white goods. The most recent comprehensive study was carried out in 1971, at which time major appliances weighed about 90 kg (Anon, 1971). A study on 1986 appliances found the average weight to be 78 kg (based on nine major appliances, U.S. EPA, 1988). Table 5.7 presents the materials breakdown of selected household appliances.

5.2.1 Iron and Steel

As calculated from the data on Table 5.7, the ferrous portion of appliances accounts for 50 percent of air conditioners and 80 to 90 percent of the other major appliances listed. Overall, it is estimated that approximately 82 percent of white goods can be recovered as steel scrap. In Ontario, this would account for approximately 77,000 tonnes per year.

Table 5.7
MATERIALS USED IN SELECTED APPLIANCES[1]
(Anon, 1971)

Appliance	Average Total Weight (kg)	Composition (% of Total Weight)					
		Steel	Copper & Alloys	Aluminum & Alloys	Glass	Polymer	Paper
Air Conditioner	56.6	50.0	28.8	8.0	-	7.2	6.4
Kitchen Range[2]	89.8	90.0	1.0	1.0	6.0	1.0	1.0
Refrigerator	147.3	80.0	3.7	2.7	3.1	10.5	-
Dishwasher	64.3	84.6	3.6	1.4	-	14.0	-
Washer[3]	113.4	82.8	1.6	6.0	0.1	2.8	-
Dryer	65.7	91.2	1.3	2.7	0.1	4.1	-

[1]Anon, 1971
[2]Also contains 1.0% kg zinc
[3]Also contains 2.6 kg concrete

The ferrous portion of appliances is in four forms:

- Painted and porcelain coated steel
- Uncoated steel
- Stainless steel
- Cast iron

Coated steel is the largest portion of the ferrous materials, accounting for about 90 percent of total ferrous metal account.

Historically, many steel mill operators were hesitant to use steel scrap from baled scrap appliances, primarily because of the porcelain coating. This material, which may account for up to five percent of the scrap weight, contains a number of trace elements (antimony, cobalt, lead, titanium and zinc) which are undesirable in steel making. A study carried out in 1978 (Kinne) showed that appliances could be shredded by automobile shredders, and the resulting scrap contained no noticeable porcelain coating. In

other words, shredding of appliances removed the coatings. This is not unexpected, since visual inspection shows that shredding also removes the coatings from automobiles.

In order to show that the appliance scrap is comparable to automobile scrap, a representative sample was melted and the chemical composition determined. All of the elements of concern were below or equivalent to those found in melted automobile scrap and well below the ATSM tentative specification for ferrous scrap recovered from municipal solid waste and destined for iron and steel production (Kinne, 1978). One Ontario shredder (Levitan, 1989) indicated that there is a relatively high copper content in shredder scrap from appliances compared to automobiles. This copper content is only sufficient to produce a negative impact in the production of high grade steel. The high copper content is primarily due to the relatively high content of copper components (ie. wiring, heat exchangers, etc.) in appliances (about three percent) compared to automobiles (less than 1 percent). These components, particularly wiring, can be attached to steel fragments and escape into the ferrous stream during magnetic separation.

5.2.2 Non-Ferrous Metal Components

As shown in Table 5.7, the primary non-ferrous metal components of appliances are copper and aluminum.

Copper is used primarily for electrical components but also for refrigeration tubing and other components. On average, approximately three percent of the total appliance weight can be attributed to copper (for air conditioners, approximately 30 percent).

Approximately four percent by weight of appliances are aluminum components.

In total, major non-ferrous metallic components recoverable from appliances are approximately seven percent of the total original weight of the average appliance.

5.2.3 Non-Metallic Materials

Organic materials (plastics) were primarily used as insulation in the production of appliances. In 1971, the average organics content of the appliances listed in Table 5.7 was about seven percent. Although there is no recent data, it is expected that organic polymeric materials have replaced a portion of metallic materials in household appliances in recent years. About three percent of the weight of appliances (in 1971) consisted of glass, paper and other non-metallic inorganic material.

One material recently developed, called NIMS (New Inorganic Materials Science) is a micro defect free substance which uses sand as filler. This material has the ability to withstand heat required for many applications, and will cut down costs and weight of

appliances. It is thought that substantial use of NIMS will be made in post-1989 appliances, thereby cutting down the use of metallics considerably (Henstock, 1988).

5.2.4 Contaminants of Concern

As indicated in Chapter 4, cadmium and lead have been detected in some shredder fluff leachate samples at levels that could classify the fluff as hazardous under Regulation 309. In order to determine if this contamination could be controlled, it is necessary to identify the sources of these materials.

As previously noted, there have been no recent studies carried out on the components of major appliances. For the purposes of this investigation, a Canadian appliance manufacturer was contacted and information regarding the use of the contaminants of concern as well as any other hazardous substances, was requested. The following information was obtained (Confidential, 1989).

Lead in appliances is contained in solder on electrical wires and refrigerator heat exchangers. Trace quantities of lead may also be found in some paints and coatings.

Trace quantities of cadmium may be found in solder and porcelain enamel. A number of years ago, some screws and bolts may have been plated with cadmium. Currently, this is not the case. Furthermore, trace quantities of cadmium and antimony may be found in galvanized steel.

The contaminants of concern to this study are those that end up in the shredder fluff stream. In the case of appliances, paints, coatings and solder are the most likely contributors to contaminants in the waste stream. Although lead solder and refrigerator heat exchangers are recovered in the non-ferrous metal fraction, small particles of lead solder can escape into the fluff stream.

5.2.5 PCB Capacitors

Capacitors containing dielectric fluid have been used in models of appliances that draw a high electrical load in order to provide a uniform supply of power. PCBs were first used in appliance capacitors over 45 years ago. This fluid was particularity suitable for this application because of its stability and non-flammability.

Under Ontario Regulation 309, wastes containing more than 50 mg/kg of PCB or that produce leachate with more than 0.3 mg/L PCB, are classified as hazardous and must be stored and managed in accordance with Ontario Regulation 11/82 and Regulation 309. Under U.S. EPA regulations, this waste is also considered hazardous.

The fear of PCB contamination of shredder fluff has only been sparked in recent years when a few U.S. state agencies sampled fluff in their areas and detected PCB above 50 mg/kg in some samples. One shredding facility in Orange County, California was even

charged with violating state disposal regulations. The shredding industry suspected white goods containing PCB capacitors to be the cause of contamination (Apotheker, 1989; Confidential, 1989).

Background Information

In 1988, the EPA attempted to obtain all available information on the use of PCBs in capacitors in household and commercial appliances and fluorescent light ballasts. Available information was obtained by subpoena to appliance manufacturers, as well as from portions of EPAs rule making records. As a result of this survey, the EPA estimated that five percent of all discarded appliances contained PCB capacitors.

I.S.R.I. refuted the EPA's estimate as being too low based on new information provided by one major U.S appliance manufacturer (Confidential 1988). This manufacturer reported that PCB-containing capacitors were manufactured from the early 1930s until July 1977. Small PCB capacitors manufactured by this firm contained essentially 100 percent PCBs. Capacitors used during this period contained predominately, but not exclusively PCBs as the dielectric fluid. In 1989, GSX Services Inc. conducted a study of PCB content of capacitor fluids. Seven different types of capacitors and ballasts were analyzed for PCBs. The PCB content of all seven was found to be greater than 50 percent (500,000 mg/L)

Small capacitors, those containing less than one kilogram of PCBs, were used in the manufacture of a variety of residential and commercial appliances. The U.S. manufacturer and a survey of Canadian manufacturers (Confidential, 1989) report agreed that in most cases capacitors were not used in the manufacturing of the following:

- Clothes dryers
- Washing Machines
- Dishwashers
- Stoves
- Hot water tanks

Furthermore, only limited use of capacitors was made in refrigerators and freezers. Reports from the observations of an ongoing capacitor removal program in Davenport, Iowa confirm these appliances to be capacitor free in most cases. However, fluorescent lights in stoves have been found to have PCB containing ballasts. Capacitors in appliances were estimated by the U.S. manufacturer to contain between 50 g and 1 kg of fluid.

Both the U.S. and the Canadian manufacturers agree that PCBs have not been used in capacitors since 1977 and that capacitors manufactured since this date are clearly marked that they contain no PCBs.

White Goods Survey

In October 1989, CH2M HILL conducted a survey of white goods being disposed at Fairfax County Municipal Landfill in Virginia, U.S.A. The purpose of the survey was to determine the proportion of different types of appliances being disposed which had capacitors, and if possible, determine whether these capacitors contain PCBs. The Fairfax County site was selected because they have an on-going capacitor removal program, and therefore the survey could be conducted by observation of their program.

A CH2M HILL staff member spent four days in Fairfax County surveying appliances that arrived to the site. The site receives waste from 1.5 million people in the County area. In four days, 281 units were processed and surveyed.

Table 5.8 presents the breakdown of white goods types received over the survey period. Refrigerators, washers, dryers and hot water heaters each accounted for about 15 percent of the total number of appliances received. Air conditioners accounted for 11 percent, dishwashers and stoves each for about eight percent, and furnaces, five percent. Florescent lights, microwave ovens and other items accounted for less than five percent of the total number of appliances surveyed.

Table 5.8 presents the percentage of each type of appliance with capacitors. Dishwashers and water heaters were the only appliances which were 100 percent capacitor free. Only five percent of dryers and four percent of stoves had capacitors. Greater than 50 percent of the furnaces and fluorescent lights had capacitors. All air conditioners had at least one but usually two or three capacitors. The small number of other items which contained capacitors included microwave ovens, a photocopier, and a refrigerated water fountain. In total, 25 percent of the 281 surveyed appliances contained capacitors.

The number of capacitors marked as containing no PCBs was also reported. Of the 70 items containing capacitors, four (or six percent) were marked, stating that they did not contain PCBs. Markings on nine, or 13 percent, were not legible.

Since the beginning of the Fairfax County capacitor removal program in February 1989, and up until August 1989, a total of 11,332 appliances were processed. The total number of capacitors removed was 1,687. This excludes those marked as being PCB free. This results in an average number of appliances containing capacitors, not marked as being PCB free, of 15 percent, compared to 21 percent of appliances with unmarked (or illegible) capacitors in the present study. The high percentage found during the short study period may be attributed to the high percentage of air conditioners processed, associated with the time of year.

Table 5.8
SUMMARY OF SURVEY OF WHITE GOODS
FAIRFAX COUNTY, VIRGINIA
(October 16-20, 1989)

Type	Total Number Surveyed	Percent of Total	Number of Applicances With Capacitors	Percent of Applicances With Capacitors
Refrigerators	43	15.3%	8	18.6%
Washers	48	17.1%	11	22.9%
Dryers	39	13.9%	2	5.1%
Dishwashers	23	8.2%	0	0.0%
Air Conditioners	32	11.4%	31	96.9%
Stoves	24	8.5%	1	4.2%
Furnace	14	5.0%	9	64.3%
Flourescent Lights	4	1.4%	3	75.0%
Microwave Ovens	2	0.7%	2	100.0%
Hot Water Heaters	44	15.7%	0	0.0%
Other	8	2.8%	3	37.5%
TOTAL	281	100.0%	70	24.9%

Note: Total number of capacitors marked as containing no PCBs: 4 or 5.7%

During the survey, the number of capacitors and approximate sizes were recorded so that the volume of dielectric fluid could be estimated for each type of appliance. These estimates are very rough, since they assume that the entire volume of the capacitor contains dielectric fluid which is a worst case assumption. Table 5.9 presents the mean estimated weight of fluid for each type of appliance with capacitors, compared to those weights provided by one appliance manufacturer (Confidential, 1988).

The weights were calculated in order to approximate the maximum potential PCB concentration of appliance shredding fluff, assuming that all of the dielectric fluid is 100 percent PCBs, and ends up in the fluff stream. Based on the Fairfax County survey results for weight of fluid in domestic appliances, and 18 percent (by weight) waste production from the total weight of appliances, the PCB level in the fluff could be up to 2,400 mg/kg. Alternatively, using the EPA estimate of capacitors in only five percent of appliances, and the average minimum literature weight of PCBs per capacitor (found in household appliances) of 0.04 kg, an estimated 142 mg/kg of PCB could be present in the fluff. Both of these estimates assume that the feedstream is 100 percent appliances. It is interesting to note that with the most conservative assumptions, potential contamination estimates presented show that fluff contamination above the 50 mg/kg level is possible in the fluff when white goods make up the total feedstream.

In order to establish the age distribution of discarded appliances, the CH2M HILL field staff member attempted to find a date or number that could identify the manufacturing date on the appliance. For the most part, this attempt was futile. By the time the white goods reached the capacitor removal site, they had been handled extensively, and were missing name plates, etc.

Age Distribution of Appliances

The data from the survey carried out by CH2M HILL in addition to data from Fairfax County, Virginia were useful in estimating the amount of dielectric fluid from capacitors that enters the waste stream. However, the survey results do not indicate what percentage of this fluid is PCB. Knowing that PCBs were no longer used after 1977, age information would allow approximation of the number of white good items containing non-PCB and PCB capacitors.

A study was carried out in 1975 to determine the service life of new and used appliances (Tippett and Ruffin, 1975). Information on life of new appliances was also obtained for 1988 (Home Service Club, 1989). Both results are presented in Table 5.10. With the exception of stoves and freezers, the life expectancy of appliances did not vary from 1972 to 1988. For the purposes of this analysis, the most conservative numbers (longest life span) will be used.

Table 5.9
AVERAGE WEIGHT OF CAPACITOR FLUID AND NUMBER OF CAPACITORS IN APPLICANCES

	Fairfax County Study Results				Literature(2)	
Type	Total Number Surveyed With Capacitors	Total Number of Capacitors	Capacitors per Appliance	Average Wt. of Capacitor(1) Fluid (kg)	Minimum Wt. of Capacitor Fluid (kg)	Maximum Wt. of Capacitor Fluid (kg)
Refrigerators	9	9	1	0.06	0.05	0.14
Washers	11	11	1	0.05	-	-
Dryers	2	2	1	0.05	-	-
Dishwashers	0	0	-	-	-	-
Air Conditioners	29	47	1.6	0.53	0.05	1.00
Stoves	1	1	1	0.11	-	-
Furnace	7	7	1	0.31	0.05	0.16
Flourescent Lights	3	6	2	0.57	0.02	0.14
Microwave Ovens	2	2	1	0.28	0.05	0.14
Hot Water Heaters	0	0	-	-	-	-
Water Fountain	1	1	1	0.06	-	-
Photocopier	1	1	1	1.13	0.34	1.00
Microwave Oven	2	2	1	0.28	-	-
Total	59	80	1.4			

Notes:
(1) As calculated from estimated volumes of capacitors removed from appliances during survey period.
(2) Confidential, 1988.

Table 5.10
SERVICE OF LIFE EXPECTANCY OF SELECTED APPLIANCES

Item	Service Life Under Original Owner (Years)		Service Life of Used Item (Years)
	1972[1]	1988[2]	1972[1,3]
Stove	12 (1.4)	16	6
Refrigerator	15 (0.9)	16	7
Freezer	20 (4)	15	9
Dishwasher	11 (1.4)	-	7
Dryer	14 (1.3)	14	5
Washing Machine	11 (0.5)	11	5

[1]Tippett, Ruffin (1975)
[2]Home Service Clubs (1988)
[3]New and used are not necessarily additive
( )Standard error

Table 5.11 shows the approximate year in which half of all pre-1977 appliances will be discarded. For new appliances, this year varies between 1988 and 1997. For used appliances, this year varies from 1993 to 2006. Since the confidence intervals for the service life of appliances are unknown, it is not possible to determine the year when virtually all of these appliances will be out of service. This exercise does however illustrate that PCB dielectric fluid will likely be in the majority of capacitors in discarded appliances until at least 1993, and will continue to be present at decreasing levels for another 13 years.

5.2.6 Summary

Approximately 95,000 tonnes of white goods are available for disposal in Ontario each year. About 82 percent of this weight, or 77,000 tonnes per year could be recovered as ferrous scrap.

Table 5.11
APPROXIMATE YEAR IN WHICH 50 PERCENT OF
PRE-1977 APPLIANCES WILL BE DISCARDED

	Approximate Year That New Appliances Will be Discarded	Approximate Year That Used Appliances Will be Discarded[1]
Stove	1993	1999
Refrigerator	1993	2000
Freezer	1997	2006
Dishwasher	1988	1996
Dryer	1991	1996
Washer	1988	1993

[1]Assumes new and used are additive

Of the remaining 18 percent of scrap appliance weight, approximately 8 percent can be recovered in a non-ferrous metal stream. The non-metallic waste stream consists of organic polymeric materials (7 percent of the original weight) and inorganic non-metallic materials such as glass, paper and dirt (3 percent of the original weight).

The suspected materials that contaminate the waste stream are lead flakes from solder and the paints and coatings that flake from the steel during shredding. These materials may contribute to high levels of lead and cadmium in leachate from fluff samples.

PCBs in capacitors in discarded appliances manufactured prior to 1977 are another potential source of contamination of fluff. Approximately 15 to 20 percent of discarded appliances contain capacitors which may contain PCBs. It is estimated that 50 percent of appliances with PCB capacitors will be discarded by 1993, and PCB capacitors will be present in a decreasing proportion for another 13 years.

Chapter 6
WASTE MANAGEMENT ALTERNATIVES

The preceding chapters indicated that contaminants such as lead, cadmium and PCBs are present in some of the materials used in the manufacturing of feedstream components. It was also shown that these contaminants can be present in the fluff stream. There is insufficient data characterizing shredder fluff presently being produced at Ontario facilities to determine the levels in the fluff. However, since the use of the contaminants of concern has decreased, and in some cases, ceased, the levels would be expected to decrease in time.

In some cases, control of the levels of the contaminants of concern to below specific limits may be required. Examples where this would be the case are described below:

- Specific requirements of the selected waste disposal method. For example, landfilling would require levels below the Reg. 309 hazardous waste limits.

- Specific requirements of the waste processor or disposer.

Furthermore, management of the shredding operation to try to eliminate the processing of some materials is necessary not only from a fluff contamination perspective, but also from an operational and safety perspective.

This Chapter presents presently used and potential methods for management of shredder operations to reduce the ultimate levels of hazardous contaminants in the waste stream, and also to minimize the incidence of dangerous materials from entering the shredder.

6.1 FEEDSTREAM QUALITY CONTROL

Control of the feedstream quality is practised throughout the shredding industry. As noted in Section 3, the main purposes of a feedstream control program are:

- To prevent materials from entering the shredder which can potentially damage the equipment, or pose a health or safety risk to shredder employees (ie. dangerous materials).

- To identify materials that increase the load weight (ie. "hidden" non-ferrous items) but do not contribute to the ferrous scrap output.

- To prevent materials of potentially contaminating nature from entering the waste stream (ie. hazardous materials)

Sufficiently high levels of lead, cadmium or PCBs in shredder fluff could cause the waste to be classified as a hazardous material under Regulation 309. Shredders in Ontario require that a number of obviously hazardous items, (including batteries, transformers, paint cans, etc.) be removed prior to shredding. However, with the exception of batteries, and sometimes battery cable clamps and lead wheel weights, not all shredders require removal of all hazardous materials that are part of typical feedstream components, such as automobiles and white goods.

The following subsections discuss feedstream control methods for reducing the levels of contaminants in the fluff stream as well as reducing the potential for dangerous goods entering the shredder.

6.1.1 Removal of Capacitors from White Goods

As discussed in Chapter 5, the problem of PCBs in shredder fluff has surfaced in the last 3 years when some fluff samples tested in several U.S. states showed levels greater than 50 mg/kg. Furthermore, preliminary calculations indicate that there is potential for producing hazardous levels in appliance shredding fluff. In response to U.S. EPA's enforcement of the hazardous waste classification of the wastes, the Institute of Scrap Recycling Industries (I.S.R.I.) issued a letter to its members in July 1988. The letter recommended that scrap processing facilities should either discontinue accepting white goods or alternatively, ensure that capacitors are removed from white goods prior to processing (shredding). In the latter case, the processor would have the option of removing capacitors at their site or requiring the supplier to remove capacitors prior to delivery to their site.

In response to the recommendation, a number of shredders in the U.S. discontinued accepting white goods altogether. This caused a major back-log of appliances in many communities, and in some instances, forced communities to landfill the appliances. However, at some locations, efforts have been made to develop realistic solutions to allow the continuation of a white goods recycling program. These solutions are primarily focused at removing the capacitors prior to processing.

Capacitor Removal Programs

The Major Appliance Pick-up Service (MAPS) decided to remove capacitors from appliances in order to encourage scrap dealers to accept the waste. Because of this decision, the firm grew into Appliance Recycling Centres of America (ARCA), one of the largest appliance recyclers in the U.S. ARCA operates in Atlanta, Milwaukee, Minneapolis/St. Paul and St. Louis. This private enterprise picks-up appliances at curbside and selects about 10 percent for resale. The remainder are processed to remove the capacitors, as well as copper parts, insulation and mercury-containing electrical switches. The market for selling the hand-picked body to metal processors is good (Goldberg, 1989).

ARCA operations make their profits by charging the homeowner to pick-up their appliances. Since landfilling of white goods is banned in areas where ARCA operates, the homeowner is willing to pay the small fee to have their items picked-up. The cost per appliance is in the $15 - $20 range (Apotheker, 1989).

In a number of other locations, the municipality has undertaken a capacitor removal program. In Madison, Wisconsin, a home pick-up service is provided at a cost to the homeowner of $16.50 (U.S.) per appliance. In Buffalo, Iowa, the capacitors are removed from the appliances, and the appliances are dropped off at the landfill, at a cost of $6 per appliance. In Fairfax County, Virginia, capacitors are removed from appliances at the landfill prior to delivery to the local shredder. By processing appliances and recycling, the County is saving $72,000 (U.S.) per year in avoided disposal costs (Lampi, Rickmers-Skislak, 1989).

In the course of the information search for this study, no shredders practising on-site capacitor removal were identified.

Issues Associated with Capacitor Removal Programs

The decision by a municipality, private business or shredder to implement a capacitor removal program is not a simple one. There are a number of regulatory, as well as practical issues associated with such a program.

In Ontario, the facility removing capacitors from household appliances would require registration under Regulation 309 as a Subject Waste Generator. In addition, there is potential that a Certificate of Approval would be required by the shredder to process wastes, under Part V of the Environmental Protection Act.

Since there are no ultimate disposal sites for PCBs in Ontario, the capacitors removed would likely be stored on-site. In this case, a certificate of approval would be required in accordance with Section 8 of the Ontario Regulation 11/82. This section states that:

> "No person shall have at a waste disposal site PCB wastes received by the person after this Regulation comes into force unless the waste disposal site is operated under a certificate of approval containing a condition referring to this section and specifying the circumstances under which PCB may be accepted at the waste disposal site."

A second consideration in the decision to operate a capacitor handling program is the issue of employee handling of PCB wastes. Under the Ministry of Labour Biological and Chemical Control Regulation 654/86, there are no specific requirements for the handling of liquid PCB wastes. In addition, it is unlikely that the time expected average

exposure values (TWAEV) for air exposure limits of 50 $\mu g/m^3$ would ever be exceeded. However, the operator may want to conduct an assessment because of the high public profile of PCBs, in order to ensure that no risks were involved.

Furthermore, it is unlikely that exposure to the liquid would occur, since PCBs would normally be contained within the capacitor. However, in the instance of leaking or broken capacitors, protective clothing and equipment should be available to the employee. In a letter to its members (September 1988), I.S.R.I. also recommended routine medical surveillance of employees potentially exposed to PCBs.

In the Fairfax County program, a local hazardous waste contractor trained the County staff to handle PCB wastes and provided personal safety clothing to use when handling the wastes. Safety equipment is only used in the removal of broken or leaking capacitors.

Other considerations in setting up a capacitor removal program are logistics, economics and incentives.

As illustrated in Chapter 3, the delivery infrastructure of discarded appliances varies between municipalities. Items may be hauled directly to the landfill, directly to the scrap dealer or directly to the shredder. If a capacitor removal program were to be undertaken, an appropriate unloading and approved processing location is required. In the U.S. municipal programs, the processing is carried out on paved areas at the landfill. In Ontario, the climate may also be a major consideration, and either a sheltered area is required, or stockpiling of the appliances for about four months per year in winter may be required.

The economics and incentives of implementing a capacitor removal program must be considered. Most shredding operations in Ontario are not dependent on appliances to produce their desired scrap output weight. Therefore, the shredder operator may find that the costs of implementing a program outweigh the benefits. Likewise for the scrap dealer. For the municipality presently landfilling the appliances, there is a definite potential of reducing the volume of landfill capacity used. In Fairfax County, for example, an annual net savings of $72,000 (Lampi, Rickmers-Skislak, 1989) was realized, after subtracting the avoided disposal cost and revenue from the collection and processing costs.

As noted previously, I.S.R.I. recommended to its members that white goods containing capacitors should not be accepted (August, 1989). If this recommendation were to be accepted by Ontario shredders, a number of municipalities, particularly in the Metro Toronto area, would be forced to consider implementing a capacitor removal program.

If all discarded appliances were landfilled in Ontario, an estimated 85,000 m^3 of landfill capacity would be consumed each year. Recycling of appliances is also a particularly significant issue considering the public climate and the existing provincial goals for

diverting wastes from municipal landfills. In order that the Province meet it's objectives to divert from the landfill 25 percent of all municipal solid waste by 1992, and 50 percent by the year 2000, recycling of white goods must be encouraged.

One possible scenario that should be looked at is legislating the responsibility for recycling to the appliance or automobile manufacturer. By the implementation of this long term solution, incentives will be created to design manufactured items for recycling. Several shredders comments indicate that his type of program would be enhanced if the shredders were to work directly with the manufacturer.

The purpose of the above discussion is to illustrate the major considerations involved in the implementation of an appliance capacitor removal program. The considerations suggest that primary focus of the shredder will be to ensure that capacitors have been removed prior to arriving at their site. The methods for quality control are discussed in Section 6.1.3.

6.1.2 Exhaust Systems and Other Lead Sources

As shown in Chapter 4, lead was present in shredder fluff collected in 1980. Levels in 20 percent of the sample leachates exceeded the Reg. 309 hazardous waste limits. In Chapter 5, the components in automobiles and appliances containing lead were presented. These are summarized in Table 6.1.

In order to decrease the potential for lead contamination of the fluff stream, the lead-contaminating components could be removed from the feedstream. Batteries, and battery cable clamps are generally removed and sold by the wrecker. In addition, lead wheel weights are not usually present because wheels are removed by the wrecker.

In California, shredder fluff is subject to a more aggressive leachate extraction procedure than the procedure used in Ontario. This extraction, using citric acid, causes more lead to leach into the extract, and thus, less lead content in the fluff is permitted. In order to ensure that the lead levels are consistently below the State requirements in shredder fluff leachates, shredders require that all batteries, battery cable clamps, wheel weights and exhaust trains be removed by the wrecker. The removal of these items from automobiles has proven successful in reducing lead levels in the fluff (Dawson, 1989).

Lead previously used in paints, coatings and body fillers in automobiles, and porcelain coatings in appliances, cannot feasibly be removed prior to shredding. However, the literature indicates that lead contribution from these sources will decrease in the future.

Table 6.1
LEAD CONTAINING COMPONENTS IN
AUTOMOBILES AND WHITE GOODS

Feed Stream Stem	Lead Containing Component	Comments
Automobiles	Batteries	
	Battery cable clamps	
	Lead wheel weights	
	Paints and coating	Use is decreasing
	Body fillers	No longer used
	Exhaust trains	Leaded gasoline users only
White Goods Refrigerator	Porcelain	Trace amounts
	Lead solder on electric wires and refrigerator heat exchangers	

In order to reduce the lead content of fluff from shredded appliances, electrical wiring and refrigerator heat exchangers could be removed prior to shredding. However, since the extent of lead contamination from these sources is unknown, and the pre-processing requirements are quite extensive, this option should only be considered if necessary.

6.1.3 Removal of Other Components

A number of components of feedstreams to shredding facilities were identified which may contain either hazardous or dangerous materials. In Ontario, shredding facilities require that some or all of these components be removed from the feedstream. A complete list of items which are considered non-conforming, was developed as part of this study. These items are categorized as follows:

- Dangerous items
- Hazardous items
- Other

Dangerous Items

The list of dangerous materials includes those materials which, through their processing, present the potential for increasing health or safety risks to employees, damaging the processing equipment or causing a dangerous situation (ie. fire). This list includes:

- Gasoline tanks (split gas tanks may be acceptable at some facilities).
- Oxygen, propane, acetylene or other gas containers.
- Unspent air bag canisters.
- Closed containers (ie. steel drums).

Hazardous Items

The list of hazardous materials includes materials which can contaminate any of the effluent streams (ie. ferrous, non-ferrous and fluff) with materials which are of undesirable or hazardous nature. These include:

- Automobile or other batteries, including battery cable clamps.
- Lead wheel weights.
- Exhaust trains.
- Radioactive material.
- Paint, solvent, or chemical containers.
- Asbestos.
- Mercury containing materials.
- PCB Capacitors.
- Electrical transformers.

Other Items

Other items considered non-conforming by Ontario shredders may include:

- Tires.
- Miscellaneous garbage including rags, paper, debris, etc.
- Miscellaneous non-ferrous materials.

6.1.4 Quality Control Methods

The previous sub-sections present alternatives for removing or eliminating items from the feedstream to avoid the potential for dangerous materials entering the shredder, and to lower the levels of contaminants of concern in the waste stream. There are two methods of ensuring that the materials of concern are removed prior to shredding. These are:

1. Processing the feedstream components on-site.

2. Requiring pre-processing prior to receiving the materials and ensuring requirements have been met on-site.

The impacts and incentives of the first method of quality control were discussed in the previous sub-sections. Where shredders decide not to process on-site because it is impractical or uneconomical, the second method of quality control must be utilized.

A comprehensive list of procedures for the shredder to follow to ensure a high degree of assurance that the materials of concern are not in the feedstream is presented below. All shredders in Ontario presently have a quality control program in place in order to prevent potentially dangerous, hazardous or extraneous items from entering the shredder. Therefore, it should be noted that many of these procedures are presently being practised at shredders in Ontario.

1. Educate the supplier about the items that require pre-processing and the reasons for processing.

2. Accept feedstream materials only from suppliers who are aware of and have consented to meet the requirements. These suppliers must be made aware of the requirement details and their responsibilities if these requirements are not met.

   In a letter to its members on the subject of capacitor removals (August, 1988), I.S.R.I. recommended that the shredder should require the supplier provide "certification and indemnification that the appliances being shipped contain no capacitors". One U.S. shredder responded by requiring that the supplier provide the removed capacitors with the delivery of his load, as a confirmation that the capacitors have been removed (I.S.R.I., August, 1988). Similar methods could be used for batteries, exhaust trains, etc.

3. Provide an inspection program of incoming loads that will also allow identification of the supplier if non-conforming items are present (eg. colour coding of components in load). The inspection program should include visual inspection on unloading, and while conveying to the shredder. In addition, where non-conforming items are not readily visible, such as capacitors, carry out random spot-checks to verify that the materials have been removed.

   In the case of capacitors, employees would require some form of training to enable them to identify which appliances may contain capacitors and where these capacitors would be located in the appliance.

4. Hold the supplier responsible for all costs and damages incurred as a result of their non-compliance.

   In a letter to its members on the subject of capacitor removal (August, 1988), I.S.R.I. recommended that if any capacitor is identified in a shipment, then the entire load should be rejected. This practice is recommended for any shipment in which a non-conforming item is found. Furthermore, if a non-conforming item is not detected until processing, for example, and an explosion occurs within the shredder, the supplier should be held responsible for all clean-up costs and damages incurred.

   Again, it is imperative that the supplier is aware of the requirements, and of his responsibility if the requirements are not met.

5. Analyze statistically representative shredder fluff samples routinely for the contaminants of concern. This is discussed in more detail in Chapter 6.5.

6.2 SEPARATION TECHNIQUES

A number of studies have been carried out on the recovery of plastics, and improving the recovery of metals from shredder fluff by using improved separation techniques. However, as yet there has been no research carried out on separating the contaminants of concern (ie. cadmium and lead) from the fluff. The research suggests that separation techniques could be used to reduce the levels of cadmium and lead in shredder fluff.

One study carried out in 1987 (Boeger, Braton, 1987) documented the size breakdown of material components of a typical shredder fluff sample produced from an air cyclone system. It was found that non-ferrous metals made up to 6 percent of the fluff weight. Of the total fluff weight, 3.4 percent were large (> 5 cm) pieces, presumably aluminum. This can be supported by the results from another study, where about 3 percent of the total fluff weight greater than 5 cm was found to be aluminum (Valdez, 1976).

Virtually all (2.1 percent) of the remaining non-ferrous metal material was in the smallest size category (<2.5 cm). Therefore, in theory, if the fluff were screened to remove the smaller particles or fines, then the non-ferrous metals of concern would also be removed. One study found that the material from a non-ferrous metal stream passing through a 1 cm screen contained paint flakes and small metal fragments (Bilbrey et. al., 1979). This result suggests that the same material would be removed from a fluff stream.

In order to determine if screening would be successful in reducing the levels of lead and cadmium in shredder fluff, an experimental program would be required. The recommended program would involve conducting Regulation 309 leachate extraction and analyses of unscreened and screened fluff, as well as the screened material (fines). Representative samples of all streams are required to verify results. One such study could be carried out at Bakermet, in Ottawa, where fluff is presently screened in the metal recovery process.

Screening of fluff to remove cadmium and lead would produce a small volume of concentrated metal screenings which may require special disposal as a hazardous waste. Alternatively, the feasibility of recovering the metals using processes such as the PUREMET process (discussed in Chapter 7) could be investigated. The remaining large volume of fluff would likely be relatively free of these metals, and thus would likely be classified as a non-hazardous solid under the Regulation 309 procedure.

6.3 SHREDDER FLUFF TREATMENT

Treatment of shredder fluff containing leachable contaminants in order to reduce their leachability is another alternative that can be considered. Only cadmium and lead were identified as the contaminants that could be extracted using the Reg. 309 leachate extraction procedure, to levels exceeding the hazardous waste limits. Thus, the treatment would be aimed at "fixing" these metals in the fluff.

Stabilization techniques involve processes that limit the solulibility of, or detoxify the waste contaminants, even though the physical characteristics of the waste may or may not be changed or improved. The process normally involves the addition of materials that ensure the hazardous constituents are maintained in their least toxic form. An example of stabilization is sulphide or lime precipitation of heavy metals.

Encapsulation goes one step beyond stabilization. It is a physical process whereby a solidification agent surrounds waste particles to bind the contaminants within the waste.

Because of the State of California's aggressive "chem-wet" leachate extraction procedures using citric acid, and the stringently regulated lead levels, all fluff in this State is processed using stabilization and encapsulation techniques before disposal. This involves the addition of lime followed by sodium or potassium polysilicate to the fluff to bind metals. The fluff is then considered acceptable for landfilling by the State Department of Health Services. The cost of treatment is estimated at $10 to $20 (U.S.) per tonne of fluff. An additional advantage to treatment is that it renders the fluff non-flammable.

Leachate extractions of the encapsulated fluff are carried out for every 1,000 tonnes, using either deionized water or landfill leachate. Contaminated levels in leachate from treated fluff do not exceed State drinking water standards (Andrushryn, 1989).

In California only the portion of the fluff less than 1 inch in size is treated by this method. The remaining lighter materials, accounting for 50 to 65 percent of the waste stream, have been considered by the State Water Board as acceptable for landfilling.

The Ontario Regulation 309 leachate extraction procedure uses acetic acid, a less aggressive acid than the citric acid used in California. Thus, the intensive control techniques used in the State of California may not be required by Ontario shredders. Therefore, less costly stabilization techniques may provide adequate stabilization of the contaminants of concern.

Large quantities of fly ash or lime are available in Ontario. Therefore, preliminary examination of this option indicates that it is feasible for the metal processor to install the appropriate equipment to mix the lime into the fluff including a lime or soda ash storage site.

The effectiveness of using lime to stabilize metals without subsequent encapsulation could not be established, since the use of this procedure was not identified in the literature search. However, the MOE have concerns about liming as a technique to stabilize metals in the fluff, since it could be considered a technique to "fool" the leachate extraction test results, and not a true stabilization method. Therefore, if this technique is to be considered an option, treatability testing must be performed.

6.4 MIXING WASTE STREAMS

As shown in Chapter 4, the levels of cadmium and lead in shredder fluff leachate from some samples may exceed the hazardous waste limits. However, the historical data show that levels are generally the same order of magnitude as the limits or lower, and do not vary widely. In addition, the levels are expected to decrease in the future, due to the decreasing use of these metals in paints, coatings and body fillers in automobiles. Furthermore, the available data indicate that levels of PCBs in shredder wastes may be the same order of magnitude as the limit of 50 mg/kg.

Mixing the shredder fluff stream with another waste stream so that the combined waste is non-hazardous under Ontario Reg. 309 is not considered acceptable waste management practice. It should be noted that mixing this stream with a material to produce a usable material, such as asphalt, is a potentially acceptable method for recycling this waste. This type of disposal option was not identified for shredder fluff in the information search.

6.5 WASTE CHARACTERIZATION

The most important aspect of establishing the hazardous or non-hazardous nature of a waste stream is the representativeness of the sample(s) used to characterize this waste stream. If the method selected for disposal of the shredder fluff requires the contaminants in the waste stream to be below specific limits, then it is imperative that a sampling methodology be developed that represents, in as far as possible, the true nature of the waste stream.

Because shredder fluff is very heterogenous, a small discrete sample (eg. 50 g for leachate extraction) is not sufficient to represent the "average" levels of contaminants in a large volume of waste. The following three procedures are recommended for enabling accurate characterization of wastes from Ontario shredding facilities:

1. Designing a sampling methodology that would provide a sample with the best possible representation of the large volume being characterized.

2. Providing a sufficient number of sample analyses to define the variability of sample results.

3. Maintaining uniformity in the sample collection, processing and analytical procedures from sample to sample and site to site.

A number of sampling protocols have been designed for collection of a representative solid waste sample from a large volume of wastes. One example is the cone and quartering technique (Chin, Franconeri, 1980).[1] Because of the small sample size required for leachate extraction, a larger sample (2-3 kg) obtained using this or a similar type of technique followed by a grinding process to reduce particle size before withdrawing the 50 g sample may be appropriate. Nevertheless, a suitable technique should be developed that can be used uniformly throughout the shredding industry in Ontario.

In Ontario, shredder fluff samples are not routinely analyzed and historically, only a limited number of samples have been analyzed. Routine sampling, leachate extraction, leachate and bulk (PCB) analyses of shredder fluff is recommended for the following reasons:

- To provide a database which allows characterization of the concentrations and variability of contaminants in shredder fluff from known feedstream materials.

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[1] This method involves shaping a bulk quantity into a symmetrical cone. The cone is divided into four quarters. Opposite quarters are discarded, and the procedures is repeated with the retained quarters. The process is repeated until the desired sample size is reached.

- To provide to the associated regulatory agencies evidence that the waste is non-hazardous in accordance with Regulation 309.

- To allow monitoring of the changing nature of the shredder wastes with time due to the changing nature of the feedstream.

- To possibly detect non-conforming items in the feedstream by detection of contaminants in the waste stream.

Since relatively little data are available to characterize wastes presently being produced at Ontario shredders, a comprehensive sampling program would be useful for establishing a database. However, the results from an on-going study being conducted by the U.S. EPA may be sufficient to establish a characterization database for components presently being shredded. These results are expected to be available in late 1990.

In order to provide data that is comparable from site to site and within sites, it is imperative that the sample collection, handling, processing and analytical procedures be uniform. Therefore, it is recommended that the details of all procedures be established and documented, and used as standards for the shredding industry.

In addition to the variability due to the sample heterogeneity, a large interlab variability between samples can result because of differences in the following factors:

- Sample preservation, storage
- Sample grinding
- Leachate extraction (ie. acid addition)
- Analytical techniques

In order to minimize the variability in sample results, it is recommended that all Ontario samples be processed and analyzed at a single laboratory.

The ultimate purpose of providing on-going characterization of the shredder fluff stream by routine monitoring is to ensure that these wastes are correctly characterized under Regulation 309, and that appropriate disposal methods are used.

6.6 SUMMARY

Table 6.2 summarizes the methods discussed for management of ferrous metal shredding wastes, to control the levels of contaminants.

Table 6.2
SUMMARY OF SHREDDER FLUFF MANAGMENT TECHNIQUES

Method	Description	Comments
Feedstream Quality Control	• Prevents hazardous materials from entering the shredder prior to processing. • For PCBs, removal of capacitors from white goods. • For lead, removal of batteries, battery cable clamps, lead wheel weights and exhaust trains. • Also, removal of all dangerous, hazardous and other materials.	• Requires extensive inspection and tracking program at the shredder. • If all shredders do not have same requirements, there is the potential for suppliers to supply to one with less stringent requirements. • Does not guarantee that waste will meet requirements for contaminant limits.
Separation Techniques	• Screening of fluff to remove particle fines, containing heavy metals.	• Work is required to verify that screening is sufficient, and to determine appropriate screen sizes. • Small volume of screened fines would likely be a hazardous waste and require costly disposal. Alternatively, metals could possibly be recovered.
Shredder Fluff Treatment	• Stabilization and possibly encapsulation of fluff or portion of fluff, to immobilize metals (lead and cadmium).	• Treated fluff has little risk of hazardous waste designation. • Further work would be required to determine the appropriate treatment for Ontario. • A capital and operating cost would be associated with treatment. • Landfilling is the only likely disposal alternative for treated fluff.
Mixing waste streams	• Mixing fluff with non-hazardous waste streams to reduce the level of the combined waste to below the Reg. 309 hazardous waste levels.	• Not an acceptable method of managing hazardous wastes in Ontario.

Table 6.2 (Cont'd)
SUMMARY OF SHREDDER FLUFF MANAGMENT TECHNIQUES

Method	Description	Comments
Waste Characterization	• Characterizing the fluff stream to determine whether feedstream control or fluff processing is necessary to reduce the contaminant levels to specific limits.	• Would provide ongoing monitoring of changing shredder fluff characteristics. • Sampling and leachate extraction techniques should be documented for uniform use in the industry.

Section 7
WASTE DISPOSAL ALTERNATIVES

This Chapter presents a review of the various waste disposal methods for shredder fluff. In addition to the range of disposal methods reviewed, the reduction of waste stream volumes by designing for recycling, is discussed.

7.1 LANDFILLING

7.1.1 Municipal Landfill

Since the beginning of the ferrous metal shredding industry and up until very recently, disposal of shredder fluff in municipal landfills was the only method of disposal used for this waste in Canada, the United States and Europe. The main reason for using this method is that no other economically feasible methods have been available for disposal of this waste. Thus, to the shredder the main advantages of sending this material to the landfill have been economic.

In recent years, disposal at municipal landfill has encountered problems, including:

- Landfills, particularly in Metro Toronto and surrounding areas, have begun to approach the capacity limits. To preserve capacity, some landfills are reluctant to accept large volume wastes.

- Landfill costs have risen at a dramatic rate in the last five years, thus reducing the profit margin for the shredder.

- Landfill operators are wary of accepting a waste whose characteristics are uncertain.

Furthermore, the provincial government, has initiated a province wide mandate to divert wastes from municipal landfills by 25 percent by the year 1992 and 50 percent by the year 2000.

For shredders in the Hamilton area, landfilling is no longer an option for disposal of shredder fluff, since the landfill that had previously accepted this material has reached its approved capacity.

In Ottawa, Thunder Bay and Windsor, landfilling is expected to be the waste disposal method to be used for the foreseeable future. However, in light of the MOE objective that the true cost of waste management at landfills be reflected in tipping fees in the near future, it is expected that costs of landfilling will rise significantly and decrease the profit margin for the shredder.

7.1.2 Landfill Cover

Solid waste placed in landfills is covered daily with soil or another material. The purpose of landfill cover is to minimize the exposure of the waste to air and wind to prevent odour, the attraction of insects and rodents and wind blown litter problems. An additional benefit of cover is to minimize moisture entering the fill. Generally, soil excavated from the landfill area is used as cover. However, in some areas where soil is not available, cover material is purchased from a quarry.

Shredder fluff has been found at some landfill operations to be an effective cover material. At the Regional Municipality of Ottawa-Carleton landfill, fluff was used as cover material until 1988, and thus, no charges were incurred for fluff disposal. In one facility in Alberta, fluff continues to be used as cover, at no cost to the shredder (Lazareck, 1989). In Thunder Bay, the shredder has proposed the idea to the local landfill.

One study was carried out in 1987 (Boeger and Braton) to evaluate using shredder fluff as a supplement to, or replacement for, daily landfill cover material. Specifically, only the fluff materials under 5 cm in size were evaluated. These smaller particles composed of rocks, sand, dirt, glass particles, plastic and various fibres, accounted for 79 percent of the total fluff volume.

Many advantages of using the <5 cm fraction of shredder fluff were identified. The major advantages included:

- The cover provided a stable and firm mat on which vehicles could drive safely.
- The material was found to prevent runoff erosion of cover material.
- The material trapped dust on dry windy days, compared to normally dusty soil cover. On wet days, the material did not stick to equipment, compared to wet soil (mud).
- The depth of cover could be reduced to 15 cm, compared to 30 to 45 cm for soils, because of its comparatively good matting. This saved considerable landfill capacity.
- The soil removed for excavation of the landfill could be reused for other purposes.

The use of shredder fluff, or at least that portion of shredder fluff under 5 cm as landfill cover appears to be a promising alternative for the disposal of shredder waste. Two main problems must be resolved prior to the further application of this alternative in Ontario. These are:

- There must be evidence that the fluff material is non-hazardous in accordance with Ontario Regulation 309. Thus, those alternatives for waste management discussed in Chapter 6 may apply.

- Landfill owners must be made aware of the advantages associated with this waste disposal alternative.

In the State of Wisconsin, where a shortage of cover materials exists, the Governor has backed a legislation that requires all landfills to accept shredder fluff and foundry sands as cover. Both materials have been found to be acceptable cover materials, and have been used for over five years. It is expected that the legislation may change in the future, because landfill owners want to be able to charge a tipping fee for fluff and foundry sand (Est, 1990).

If this option were to be considered for the Ontario shredding industry a pilot study should be conducted in Ontario, which will provide more information on the use of fluff as landfill cover. Successful results from a pilot study would provide good incentive for landfill owners, particularly those with cover material shortages, to accept fluff as cover material.

7.1.3 Dedicated Landfill

In this report, a dedicated landfill refers to a landfill designed for and containing only shredder fluff material. There are at least three dedicated landfills in operation, in Ontario, Quebec and the State of Michigan. Each of these are owned and operated by a single shredder.

In order to describe the general features of a dedicated landfill, information on the LASCO Industrial Metals facility in Whitby, Ontario is used (ORTECH, 1989). This facility has been operating on an experimental basis since 1987 and is presently undergoing an environmental assessment under the Environmental Assessment Act, for approval to operate for the next 20 years. For this particular project, the landfill proposed will surround the property as a berm. Thus, a secondary benefit will be to act as a visual and noise shield around the industrial operations on-site for the neighbouring community.

The primary engineering features of this berm, similar to those of a municipal landfill, include:

- Excavation below ground level 1.5 to 2 m.

- Leachate collection and drainage systems.

The unique features of a dedicated berm are:

- No daily cover is required since the fill material does not attract insects or rodents and cannot erode.

- Fire prevention is required. Fire walls, made of soil 2-3 m thick were used to separate cells at LASCO. In dry weather, water may be sprayed on the berm to reduce the potential of spontaneous combustion. The risk of fire is only slightly greater than for municipal landfills for recently shredded material. The core temperatures measured in the berm at LASCO were 26 to 32 °C compared 27 °C for stabilized anaerobic municipal wastes.

The leachate runoff from the berm has been shown to be of acceptable quality to discharge to the sanitary sewers (Wesolowski, 1989). The shredder fluff structural properties are stable enough to support the weight of the dump trunks. The fill material compresses to about 1,100 kg/m^3 within the berm.

There are a number of advantages that are associated with the LASCO berm alternative. These include:

- Because this waste is non-biodegradable, the potential exists for recovering the compacted waste for recycling or ultimate disposal, if a viable solution (eg. incineration) becomes available in the future.

- If the landfill is owned by the shredder, transportation and disposal costs are greatly reduced.

- Low maintenance and operation costs.

The primary disadvantages to a dedicated landfill are:

- The cost of land is high, and land area in the proximity of some shredders may not be available.

- An environmental assessment, either under the Environmental Assessment Act or the Environmental Protection Act will be required, at the expense of the dedicated landfill owner. There may be public opposition.

The dedicated landfill option for shredder waste is one with definite potential, as demonstrated by the LASCO berm. However, due to land requirements, and the high cost of land, this option may not be available to every shredder in Ontario.

7.2 DIRECT PLASTICS RECYCLING

The use of plastics in the automotive industry has increased at a rapid rate. It is estimated that in 1988, one million tonnes of plastics were used in the manufacture of automobiles in the U.S. Table 6.1 presents a typical breakdown of the components of the shredder fluff stream (Valdez, 1976). As shown, plastics make up only about 14 percent. Organic materials, including foams, fibres and rubber constituted about 44 percent of the fluff. Another study reported 14 percent plastics an a total of 66 percent organic materials (Dean et. al., 1975).

Table 7.1
THE COMPOSITION OF SHREDDER BY-PRODUCT STREAM[1]
(Valdez, 1976)

Material	Composition
Non-ferrous metals	2.7 %[2]
Ferrous metals	9.4 %[2]
Plastics	13.7 %
Foam	11.7 %
Rubber	2.1 %
Fibre	15.4 %
Paper	4.6 %
Glass	4.7 %
Dirt	7.9 %
Other	26.7 %
	100.0 %

1 Shredding of 5 GMC cars and one Volkswagen, produced in the mid-70's.

2 More recent results from one Ontario Shredder indicate that ferrous and non-ferrous metals are present in much lower proportion, <5 percent and <1 percent respectively (Wesolowski, 1990).

A wide range of plastic materials can be found in the plastics and fibre portions, including both thermoplastics, thermosets and composite materials, eg. glass reinforced polyester[1].

Each type of polymeric material found in the complex mixture has its own properties. Although reuse of some polymers appears feasible, reasonably clean and homogeneous plastic fractions are required. Thus, separation of the various types of materials is a prerequisite to plastics recycling.

A method of separating the polyurethane foam portion was found to successfully recover 70 to 80 percent of the original foam content. This method used an air suction procedure. Work done by the Ford Motor Co. demonstrated a process for converting polyurethane foam into potentially reusable products (Mahoney et. al., 1974). The foam is reacted with superheated water at 200 °C which converts it to a dense liquid made up of toluene diamines and polypropylene oxides. These components can be separated, and some can be reused in the production of polyurethane foam. Furthermore, the toluene diamines are marketable, as they are used in the synthesis of other organic chemical compounds. There has been no full-scale application of this process, and it is not known if it is economically viable (Berger, 1989).

The work that has been carried out on the separation of the other components of plastics has been less successful. The U.S. Bureau of Mines developed a method using sink-float separations with water and brine media. Concentrates of various plastics could be produced. However, clean separations (ie. homogeneous concentrates) were not produced (Bilbrey et. al., 1979; Valdez, 1976).

More recent literature has recognized that while some success has been achieved in the study of plastics separation, a number of technical and economic problems are associated with the recovery of homogenous polymeric fractions (Curlee, 1985; Kistle, 1984; Wutz, 1987). These include (Menges et. al., 1988):

- Even if a plastics mixture could be separated, a high percentage of substances, as well as incompatible polymer materials, paint residues, etc. would contaminant the mix.
- The shredder fluff comprises less than 60 percent plastics, which in addition are highly contaminated.
- The plastics obtained from the shredder fraction can only be recycled into lower grade products.
- There is only a limited market for such products.

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1 Refer to Chapter 5 for more details on the plastics content of automobiles.

Other potential techniques have been identified for recycling of the heterogenous mixture of polymeric materials, allowing one more cycling of the material before disposal is required. These techniques are discussed below.

Mixed Plastics Recycling

Recycling of the heterogenous unsorted shredder fluff mixture is a technique that may be more promising for this waste. This method involves using the heterogeneous plastic materials in a physical admixture. A number of applications of this type of mixed plastics recycling, referred to as melt homogenization, have been identified.

A recent review of three firms that lead in the development of recycling of mixed plastics was carried out (Brewer, 1987). These firms are Advanced Recycling Technology of Brakel, Belgium; Plastics Recycling Inc., of the U.S.; and Recycloplast of Germany.

All three firms operate on the basic principal that wastes will contain 60 percent of polyolefins, which hold other materials as fillers in the end products. A large percentage (15 percent) of non-plastic contaminating materials (paper, wood, textile, grit, metals, etc.) can be tolerated by the process. The stable, molded products of these operations are used in such applications as posts, stakes, manhole covers, flooring sheets, etc.

The application of this technology to municipal polymeric wastes has been found to be successful because polyolefins are the dominant types of plastics found in municipal wastes stream. Examples include milk jugs, detergent bottles and plastic bags. Application to shredder wastes also appears to be promising. However, with the costs of the necessary separation of polymeric and fibre waste from the fluff to achieve a maximum 15 percent non-organic materials, this alternative is not yet considered to be economically viable.

Research has also been carried out on recycling the entire fluff stream into a stable material that could be used for fence posts, insulating material and particle board (Machine Design, 1984). The research, sponsored by the U.S. Department of Energy, was aimed at mixing clean, ground shredder fluff with plastic binders such as melamine and phenolic-resins. There were no applications of the approach found in the information search.

If recycling of the mixed plastics stream were feasible for shredder fluff, its use may still be prohibitive for economic reasons. The products of mixed plastics recycling compete with low cost products made of plastics, clay, brick and ceramics. For this reason, a number of firms in Germany have discontinued recycling other types of mixed plastics streams (Menges, et. at., 1988). Therefore, it is unlikely that there would be sufficient economic incentive to pursue this method of recycling for shredder waste.

Summary

Direct recycling of individual polymeric materials is not yet technically feasible since separation methods cannot produce homogenous streams from the complex mixture in shredder fluff. One successful application has been identified, in the separation and hydrolysis of polyurethane foam to produce useful products. However, the economic feasibility of this technology is unknown.

Recycling of the mixed polymeric materials by melt-homogenization or chemical binding appear to be technically promising solutions. However, full scale applications have not been reported and it appears that there would not be sufficient economic benefit to recycling the plastics portion of shredder fluff in this manner.

7.3 WASTE RECOVERY

In this context, recovery is defined as the processing of wastes to recover valuable products. Two potential technologies were identified for the recovery of shredder fluff; hydrogenation and pyrolysis.

7.3.1 Hydrogenation

Hydrogenation is a process whereby organic wastes are heated in a high temperature, high pressure reactor in the absence of oxygen and surplus of hydrogen. Oxygen released from the waste becomes bound to the hydrogen, and therefore oxidation of the metals in the waste does not occur. The end products from hydrogenation include fuel gas, oils and a solid residue. Figure 7.1 presents a diagram of the hydrogenation process.

The oil fraction can subsequently be processed by the usual refinery methods, eg. into gasoline, fuel oil or other products. The gases formed in the process require scrubbing and neutralization before being used as fuel gas. The solid residue must be disposed of. One sample of mixed plastics resulted in hydrogenation products composed of 65 percent oils, 17 percent fuel gas and 18 percent solid residue (Menges et. al., 1988).

The hydrogenation process was used at least 50 years ago for the recovery of oil from coal. Union Rheinische Braunkohlen Kraftstaff AG, Wesseling of Germany have recently taken up the process for the recovery of mixed plastics wastes. Laboratory tests have shown that there is promise for mixed plastics wastes and a pilot plant is in the planning stage (Menges et. at., 1988). However, the use of hydrogenation as a possible process for shredder fluff, although promising, is still in the theoretical stage. Although it is unlikely to prove feasible in the short term, research advances should continue to be observed.

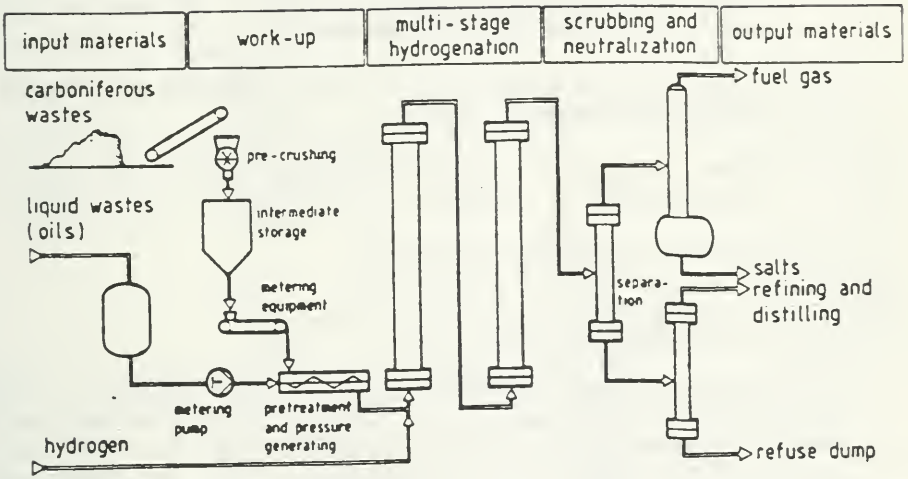

Figure 7.1
HYDROGENATION PROCESS
Source: Menges et. al. (1988)

7.3.2 Pyrolysis

Pyrolysis is the term used to describe the process of heating an organic substance in an oxygen-free atmosphere to split it into gaseous, liquid and solid fractions. Splitting occurs through a combination of thermal cracking and condensation reactions. The reaction is highly endothermic. Figure 7.2 presents a pyrolysis process diagram.

The products resulting from pyrolysis include:

1. A gas stream, primarily hydrogen, methane, carbon monoxide, carbon dioxide, and various other gases. Some of the gas stream can be recycled for heating the reactor, while the remainder can be used as fuel.

2. A valuable tar/oil stream which may contain chemicals such as acetic acid, acetone and methanol.

3. A char, containing pure carbon and other inert materials (ie. metals), which requires disposal.

Two types of pyrolysis systems are available:

- Fluidized bed
- Rotary tube process

The fluidized bed process contains a layer of sand in the combustion area. A stream of air or inert gas is passed upwards at such a pressure to fluidize the layer. The waste materials are placed on the bed resulting in mixing of the sand and waste. The closed reactor containing sand and wastes is heated to 600 to 900 °C. For plastics wastes, the end products are about 44 percent gases, 26 percent oils and 30 percent solid residues (Menges et. al., 1988). One study conducted on small batches of shredder fluff in a fluidized bed reactor yielded 19 percent gases, 34 percent oils and 47 percent solids (Wingfield et. al., 1981).

The rotary tube process, illustrated in Figure 7.2, is designed exclusively for the recovery of fuel gas. The waste is mixed in the combustion tube at a temperature of around 450 °C, resulting in the carbonation of the waste to form gas and solid residue. The residues are relatively inert. The gas must be cooled and scrubbed to be suitable for fuel, some of which can be recycled into the process, whilst the remainder is sold (Menges et. at., 1988).

In Germany large scale demonstration plants employing both the fluidized bed and rotary tube pyrolysis process have been operated since the early 1980s. Although the pyrolysis processes appear to be suitable for the recovery of organic shredder residues, the results from trials in the experimental plants are not yet available. Thus, the economic feasibility of operating full scale plants cannot be determined. At University of

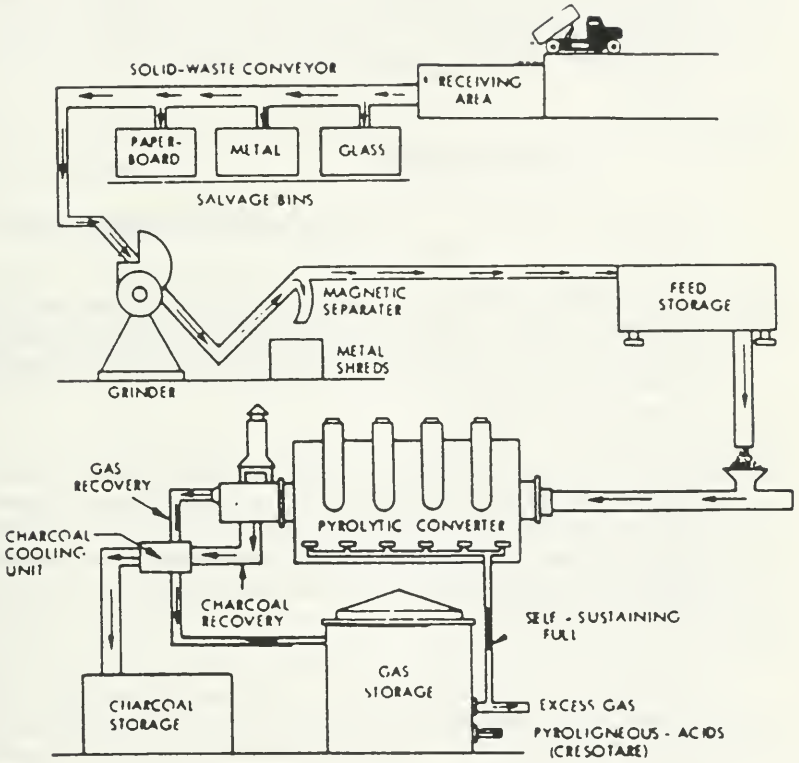

Figure 7.2

PYROLYSIS PROCESS

Source: US EPA (1973)

California at Berkeley, an on-going study is continuing investigations of the pyrolysis alternative for mixed shredder wastes (Andreshyn, 1989).

Pyrolysis of heterogeneous waste from the shredding industry appears to be promising. However, a greater understanding of the processes involved with mixed wastes is necessary to enable the reclamation of valuable materials from shredder fluff (Kistle, 1984; Wutz, 1987). Furthermore, successful pilot scale operations remain to be evaluated to determine the economic feasibility of operating a full scale plant (Menges et. al., 1988).

7.4 INCINERATION

Two main benefits can be derived from the incineration of shredder fluff, including volume reduction and energy recovery.

The incinerability of non-metallic portions of the automobile has long since been acknowledged in the scrap processing industry. Prior to the development of automobile shredding, non-ferrous components were removed from the automobile hulk by a combination of hand dismantling and open burning. Air pollution regulations lead to the development of incinerators.

Beginning in the early 1960s, several different types of incinerators were built by the auto scrapping industry. These ranged from small pit-type incinerators which burned 10-15 cars per day, to large, conveyerized, kiln-type burning chambers which burned more than 300 cars per day. Most of these incinerators failed because they were poorly designed, or the high operating costs were prohibitive compared to the costs of shredding (Dean, 1971).

In 1979, Bilbrey et. al. identified that the recoverable combustibles from an automobile were equivalent to 70 to 90 kg of coal. However, the incineration alternative was felt to be undesirable because the combustion of chlorinated plastics (ie. PVC) would result in the generation of hydrochloric acid, the emission of which would be prohibited in most areas by air-pollution regulations (Bilbrey et. al., 1979. Mahoney, et. al., 1979).

Of most concern in the incineration of automobile shredder fluff is the HCl emissions and acidity contributed from the burning of PVC wastes. In Europe, a wide divergence of opinion exists on the extent to which PVC contributes to the emission of HCl from incinerators. One report showed that estimates range from 0-75 percent of HCl emissions and 0.1 to 2.2 percent of total potential acidity in emissions from municipal wastes incineration are attributable to PCBs (Lightowlers, Cape, 1986). PVC accounts for an estimated seven to 10 percent of all plastics in automobile residues (Curlee, 1985). This is a much higher percentage than would be found in municipal wastes, which have a total plastics content of 2 to 8 percent. Therefore, it is expected that the burning of shredder wastes would produce higher levels of HCl and total acidity than from municipal wastes.

In 1984, Knistle wrote that the problems feared earlier with respect to toxic emissions, corrosive materials etc. are not severe. Modern incinerator technology, including carefully designed combustion chambers, precipitators, and scrubbers can eliminate these problems. It was suggested that, at the very least, the auto shredder fluff could be added to incinerator input stock (e.g. municipal solid waste) to allow significant caloric enrichment. However, the costs of air emissions control might be prohibitive in the use of an incinerator as an economically feasible solution to shredder fluff disposal.

In the following sub-sections, the technical details of incineration are discussed and full scale studies of incinerating shredder fluff are presented. In the final section, possible types of incinerators specifically suited to shredder fluff are discussed.

7.4.1 Incinerability of Shredder Fluff

Two pilot studies on the incinerability of shredder fluff were identified in the literature. The first, carried out by Wolman et. al. (1986), studied the operation of a prototype rotary kiln incinerator. The second study, carried out by Boeger and Braton (1987) examined the caloric output and ash residue of various size fractions of the waste.

Instigated by the prediction of severe landfill capacity shortages, and the prospect of energy recovery from the energy rich shredder fluff, Wolman et. al. (1986) performed a study to identify the energy value and operate a prototype rotary kiln incinerator with energy recovery. For this study, the energy value was measured for representative samples, taken using cone and quartering techniques (Chin, Franconeri, 1980), from 12 U.S. shredding facilities. The results showed a mean energy value of 12,560 kJ/kg for as-received fluff with a fairly wide variation due to variations in ash and moisture content. The energy value of the combustible fraction was relatively uniform in all samples, averaging 27,800 kJ/kg. This compares to about 10,500 kJ/kg for municipal solid wastes and 30,000 kJ/kg for coal.

Boeger and Braton (1987) sorted the shredder fluff by size. On a dry basis, the following energy values were measured:

Size	Energy Value	Ash Content
>1.9 cm	16,600 kJ/kg	37.4%
>5 cm	25,000 kJ/kg	22.6%

Thus, this study indicated that greater energy recovery could be achieved from the larger size fraction of the shredder fluff. However, in this study, this fraction (>5 cm) accounted for only 21 percent of the total fluff weight.

Another study (Confidential, 1985) also found that higher energy value was available in the larger sized fraction of shredder fluff. In this study, the screen size used was 8 mm. The average energy values of the two portions of fluff from 3 shredding facilities were:

Size	Average Energy Value	Average Ash Content (@ 450 °C)
Total Sample	10,768 kJ/kg	65%
>8 mm	16,537 kJ/kg	47%
<8 mm	5,754 kJ/kg	82%

The >8 mm portion accounted for 35 to 70 percent of the total fluff portion, depending on the shredder.

To summarize, the studies show that the combustible fraction of shredder fluff has caloric value similar to that of coal. Greater per unit energy value can be recovered if the fluff is screened to remove fine particles. An ash content of up to 65 percent of the original weight has been found, corresponding to an ash volume upon combustion in the range of 20 percent. The ash content for the larger sized fraction is lower than for the total fluff stream.

7.4.2 Incineration With Municipal Wastes

The two shredding facilities in Hamilton, together with a few other scrap metal processors, investigated alternatives for the disposal of their wastes after Steetly Landfill, used historically, reached its approved capacity limit and could no longer accept the waste.

The primary alternative investigated was the incineration of the fluff in the SWARU municipal incinerator in Hamilton operated by Laidlaw Environmental Services Ltd. (formerly Tricil). With the aid of an outside consultant, and the permission of the Regional Municipality of Hamilton-Wentworth, test burns of shredder fluff were conducted in 1989.

Although approval was not required because the feedstream is within the description on the existing Certificate of Approval by the MOE, and would not be required if this waste were to be burned on a regular basis, MOE was kept informed about the tests.

The main purpose of the investigation was to determine whether the burning of shredder and other scrap metal processing fluff was viable at SWARU. Thus, scientific investigations, such as heat value etc. were not carried out. In addition, leachate tests were not carried out on the fly ash or bottom ash.

The test burning examined the materials handling aspect as well as the incinerator performance using different ratios of fluff to municipal solid waste. The results indicated that burning of fluff in the municipal incinerator could be a feasible solution, with some materials handling equipment modifications.

7.4.3 Potential Incineration Technologies for Shredder Fluff

A 1990 study prepared by the U.S. Centre for Materials Production (Schmitt, 1990) presented a review of the suitability on a number of incineration technologies for the energy recycling of shredder fluff. These technologies, as well as other identified in the literature search, are reviewed briefly in this section.

This review is included to indicate possible directions for research of (a) long-term solution(s) to the shredder fluff disposal problem. In addition to the technological feasibility, other factors that will affect the implementation of any of these processes include the economic incentive by a shredder or group of shredders, the location, ownership and users (i.e. other waste producers) of such a facility and the political climate surrounding the specific setting of an incinerator and subsequent effect on the Environmental Assessment required to obtain approval to operate.

Appendix B presents descriptions of each of the incineration technologies identified in the literature as applicable or potentially applicable to shredder fluff. These technologies and their applications to shredder fluff are summarized below:

Rotary Kiln Incineration - A pilot study, using this technology showed that 94% of the combustibles could be removed in the kiln, and an 80 percent volume reduction was achieved (Woleman et. al., 1986). Leachate extracted from the ash could potentially contain metals in excess of the hazardous waste limits.

Pure Oxygen Incineration - Although not demonstrated using shredder fluff, this process has been used in Germany for reprocessing car batteries. Main advantages to this process include the reduced plant size requirements and the reduced tendency for the formation of organic pollutants (i.e. dioxins) compared to air systems (Menges et. al., 1988).

Fluidized Bed Incineration - Energy Products of Idaho (EPI) - (Albertson, 1989) have developed a unique fluidized bed system for the combustion of shredder fluff. If emissions testing results are successful, then commercialization of this technology is expected.

Plasma Incineration - Electric Plasma incineration technology has been demonstrated by Retech as successful in achieving volume reduction in the processing of radioactive wastes and contaminated soils, and producing a vitrified slag (Eschenbach et. al., 1989). The U. S. Electric Power Research Institute (EPRI) have used this technology to treat landfill material (EPRI, 1988). It is thought that plasma incineration could be used for combustion of shredder fluff, producing a glassy slag encapsulating hazardous metals (Schmitt, 1990). Ontario Hydro has a pilot scale electric furnace facility at the Lakeview Generating Station that would be suitable for testing the plasma technology using shredder fluff (Simpson, 1990).

High Temperature Gasification (HTV) Process - A patented process, the VOEST-ALPINE HTV process has been shown to convert shredder fluff into a clean fuel gas and vitrified slag (Freimann, 1989). This process is being offered for sale worldwide.

Ashes from some incineration processes, e.g. rotary kiln, fluidized bed, etc. could produce leachate with metal levels exceeding regulation hazardous waste limits and thus, would be expensive to dispose of. Included in Appendix B is a discussion of two processes identified for vitrification of shredder fluff ashes. These are:

Submerged Arc Melting - The deTOX$_{TM}$ process uses cold-top submerged arc melting to produce a vitrified glass/ceramic type product (Schmitt, 1990). This process could be retro-fitted to existing incineration units for processing ash, while returning gasses back to the incinerator for cleaning. A pilot demonstration unit is being constructed in the U.K. Resorption Canada, in Ottawa has a pilot scale submerged arc furnace with potential suitability for testing this process using shredder fluff or shredder fluff incinerator ash (Simpson 1990).

PUREMET Process - The PUREMET Process involves dissolution of non-ferrous metals followed by electrowinning recovery of metals from non-ferrous metal scrap. It is thought that shredder fluff incinerator ash could be treated in the same manner to recover non-ferrous metals (Schmitt, 1990).

7.5 FLUFF AS FUEL SUPPLEMENT IN CEMENT KILNS

Raw materials for cement making include limestone, silica and alumina from clay, shale or sand, and iron from iron ore or steel making scale. These materials are ground, blended and homogenized into kiln feed.

Three basic types of cement kilns are currently in use: wet process, dry process and preheater/precalciners. In the wet process, the crushed materials are ground with water to make a slurry, which is fed to the kiln. In the dry process, the dry, ground homogenized material is sent to the kiln. Newer mills use pre-calciners, to improve the thermal efficiency of the process.

Cement kilns are slightly inclined (3° - 6°) so that material entering at the upper end travels slowly to the firing end. The kiln rotates at 50 to 180 revolutions per hour. The final product formed, called clinker, consists of hard granular masses from 3 to 20 mm in size.

Several thermal zones exist in the kiln. At the highest end is the drying and preheating zone, where material is heated to about 800 °C. Carbon dioxide is driven off from the limestone at about 1,000 °C in the calcining zone. In the burning zone, or clinkering zone, chemical reactions occur for clinker formation to take place.

A material temperature of 1,450 °C must be achieved for clinkering to occur, which requires flame temperatures of over 2,000 °C. Gases from the kiln, consisting primarily of nitrogen, carbon dioxide, and water flow through electrostatic precipitators or bag-house filters for entrainment of particulates. Sulphur and nitrogen oxides are trapped by the alkaline nature of the kiln material. In addition, ash resulting from non-combustible material is retained in the clinker.

The cement manufacturing industry is one of the most energy intensive in Canada. Energy costs account for 20 to 25 percent of manufacturing costs. In Canada in 1987, 53.3 million gigajoules ($1,0^{12}$ kJ), equivalent to 2.0 million tonnes of coal, were used in the production of cement (Engineering Digest, 1989).

Cement manufacturing industries in Ontario have achieved fuel flexibility to enable the selection of energy sources (ie. gas, oil or coal) based on cost. As energy costs increase, it appears that the next major effort to reduce energy costs will be with waste derived fuels. In Ontario, waste derived fuels such as waste oils, wood wastes, etc. are presently being used to supplement traditional fuels in some cement manufacturing locations. One article estimated that if 100 percent of the combustible hazardous wastes generated in Canada were used as fuel in the Canadian cement industry, only 47 percent of the cement manufacturing fuel needs would be satisfied (Engineering Digest, 1989).

In Europe and the U.S., cement plants are using waste oils, spent organic solvent, and used tires as fuel supplements.

The use of waste derived fuels and organic wastes as supplement to traditional fuels offers many advantages. Specifically, the following economic advantages may be realized (Engineering Digest, 1989):

- Imported fuel volumes can be reduced.
- Non-renewable resources are conserved.
- Manufacturing costs are reduced since wastes are low cost or free compared to costly fossil fuels.

- Reduction in disposal costs for wastes that would otherwise be disposed, for example, in landfills, without any recovery.

- Possible reduction in transportation costs.

Other potential advantages include:

- The high temperature and residence times required for clinker formation are sufficient for destruction of even stable compounds. For PCB destruction, a 2 second dwell time, at 1,200 °C is required (Environment Canada, 1987), compared to 3 seconds at 2,000 °C for the gas in a cement kiln. Test burns have showed the ability for cement kilns to destroy PCBs.

- The alkaline contents of the kiln trap hydrogen chloride and sulphur oxides formed during the combustion of chlorinated wastes.

- Ash from incombustible materials on the waste such as metal, becomes incorporated in the clinker, thus eliminating ash disposal problems.

- There is no significant change in the quality of emissions when waste derived fuels are used to replace fossil fuels.

European Study

In Europe, an extensive study of the utilization of shredder fluff in the cement manufacturing industry was carried out (Confidential, 1985). The study involved two phases. In the preliminary phase, shredder waste, accounting for about 10 percent of the fuel requirement, was used at a cement plant in Germany for 12 weeks. The preliminary test results indicated the following:

- The incineration of shredder fluff did not deleteriously effect emissions from the plants.

- Metal levels in the clinker, with the exception of copper and lead, were not significantly different.

- The chloride content, grindability, compressive strength (up to 29 days) and setting behaviour of the cement was not significantly different from those where shredder fluff was not used.

The second phase involving a pilot study at a second cement manufacturing facility took place over a two year period beginning in 1982. This facility was selected because equipment for supplemental fuel feed of whole rubber tires was already in place.

In the first part of this phase, two main problems observed included material handling and customer complaints of changing cement colour.

Because of the results from the first test, a pre-processing stage was developed to improve the suitability of the shredder fluff for cement manufacturing. It was experimentally determined that by removing fluff particles less than 8 cm size by screening, much of the non-combustible material was removed. Thus, the remaining "coarse" material (>8 cm size), accounting for an average of 50 percent of the total, was suitable for fuel in the cement kiln. Therefore, the remainder of the pilot study was conducted using only the coarse material. The use of only coarse fluff eliminated to a large extent the materials handling problems.

The main conclusions of the pilot study are presented below:

1. In order to meet the silica ratio and lime saturation factor (LSF) requirements for the concrete, some adjustments to the raw feed materials were required, when shredder fluff was used as a fuel supplement.

2. Setting, soundness and compressive strength requirements were all met by the cement made using shredder fluff as fuel supplement.

3. The chloride content requirements of the cement limited the maximum amount of shredder waste that could be added as fuel. In this study, a maximum of 6 to 15 percent of the total fuel requirements (based on chloride limits of 0.05 percent and 0.1 percent in cement) was calculated.

4. The concentrations of regulated parameters in emissions during shredder usage were up to double those for the reference period. However, all concentrations were up to 2 orders of magnitude below the limits permitted.

An economic analysis was conducted in the study to determine whether the use of shredder fluff was economically feasible in the German cement manufacturing industry. The assessment included the fuel savings, the initial investments for fluff transport and storage, and the materials feed equipment. Based on this analysis, the use of shredder fluff as fuel substitute is economically feasible.

Menges et. al. reported in 1988 that cement plant operators in Germany have not demonstrated enthusiasm for using shredder fluff as fuel. However, the authors indicated that this could change if financial incentives were created.

Feasibility in Ontario

The feasibility of using shredder fluff from Ontario ferrous metal shredding industries in the cement manufacturing industry can be examined from a number of perspectives. These include:

1. The proximity of cement manufacturers in Ontario the shredding facilities.
   In Ontario, there are a large number of cement industries, with locations in Mississauga, St. Mary's, Bomanville, Woodstock and Toronto. These locations would be within reasonable proximity of the two Hamilton plants and the plants in Toronto, Mississauga, Whitby and Windsor.

2. The capacity for the Ontario cement industry to utilize shredder wastes.

   There is a total kiln fuel demand of 23 million GJ of energy per year by Ontario cement manufacturing industries (Engineering Digest, 1989). This compares to a total available energy from shredder fluff of 3 million GJ available from all of the shredder fluff produced in Ontario. Thus, if all Ontario shredder fluff were used in the cement industry, only about 13 percent of the energy demand of the Ontario cement industry would be met.

   This preliminary estimate shows that the Ontario cement manufacturing industry has the capacity to utilize a large portion of the shredder fluff produced at Ontario metal shredding facilities.

3. The composition of Ontario shredder fluff and possible pre-processing requirements.

   To date, studies have not been carried out to determine the incinerability, energy content, ash content, chloride content, etc. of fluff from Ontario shredding facilities. Furthermore, fluff particle sizes may vary from the European findings and even from site to site within Ontario, as a result of the various types of shredding equipment used.

   Therefore, if this option were to be considered, these factors would have to established for the waste being considered.

4. The materials handling requirements for the cement manufacturing industry.
   The physical characteristics of shredder fluff make its handling awkward. Thus, as identified in the European study, special handling facilities for plants not equipped for solid waste derived fuel use, or modifications to existing waste derived fuel handling facilities would be required. In addition, fluff storage and transportation requirements would need to be fulfilled.

5. The legislative requirements for the cement manufacturing industry.

   Under the Ontario Provincial Regulations, the cement manufacturing industry is required to meet Regulation 308 emission requirements. The existing data indicates that these requirements can be met with fluff as a fuel substitute.

   Under the Environmental Protection Act, the cement industry that elected to burn shredder fluff could be considered a waste disposal facility. Therefore, in order to operate, a new certificate of approval under Part V of the Environmental Protection Act would be required, which involves an environmental assessment. This could be a time and cost consuming venture.

Based on the results of the German study, it appears that burning shredder fluff in cement kilns in Ontario is a technically viable solution. The willingness of the Ontario cement industry, to consider this option should be determined. An economic and technical analysis should also be carried out to establish whether this method of fluff disposal would be economically feasible in Ontario.

7.6 DESIGN FOR RECYCLING

Although feasible recycling, recovery and disposal alternatives for the non-metallic wastes from the ferrous metal shredding industry are crucial, the more effective long term solution is to design automotive and appliance plastic components with recycling in mind. The automobile manufacturing industry is just beginning to take steps in this direction.

One firm, G.E. Plastics of Massachusetts, is working on the development of plastics that can be readily recycled. G.E. Plastics will buy back materials manufactured at their plants for recycling. Some of their applications include headlamps molded from LEXAN™ resin, and bumpers from EXNOY™ resin (Berger, 1989).

General Motors (G.M.) of Canada Ltd. in Oshawa, Ontario has developed panels for a new line of mini vans that they hope to recycle (Romain, 1990). Trial runs, beginning in June 1988, have tested pyrolysis of the panels to obtain valuable end-products. These products could be used for filler in new plastics formulations, other composites and adhesives, and as filler in other materials such as concrete and shingles. G.M. states that the panels can be easily shredded and fed into a pyrolysis unit.

A "recommended practice" tool developed by the Society of Automotive Engineers (SAE) will also provide aid in plastics recycling. This tool would involve the coding and marking of plastic components during manufacturing, to aid in recycling of components. This practice is presently used only minimally in the industry (Berger, 1989).

An extensive study carried out by Henstock (1988) examined the question of designing automobiles and appliances for recycling. Some of the main recommendations are summarized below:

- Widespread replacement of one material by another should not be undertaken without examining the implications of the secondary materials industries.

- The replacement of valuable materials, such as steel, with those which presently have no scrap value, eg. plastics, and the implications on recyclability should be considered at the design stage. No material should be introduced without considering its ultimate disposal.

- No new substance, especially any known to be toxic, should be used without giving consideration to the problems of recovery and potential for hazardous waste generation.

One German paper (Menges et. al., 1988) pointed out that there may be a negative side of designing for recycling. That is, most plastics components (eg. bumper, dashboard etc.) are frequently composites, made up of various thermoplastics, as well as fillers, reinforcements and metal parts. Thus, the costs of dismantling, collection, storage and transportation of these parts would be prohibitively high. Furthermore, if only some expensive plastics components were designed for recycle (such as at G.E. Plastics and G.M., above), this is likely to amount to less than 5 percent of the shredder fluff. Thus, the economics would scarcely justify labelling of plastics types for such a small volume reduction.

The major roadblock to progress in designing for recycling is the incentive to manufacturers. As long as the manufacturer is not directly responsible for the costs of disposing of his products, he will not be inclined to design products that are more easily dismantled and with recyclable components. Therefore, ultimately the long-term solution will require the manufacturer to assume responsibility for the disposal of discarded products.

7.7 SUMMARY

Table 7.1 presents a summary of the shredder fluff disposal options discussed in this Chapter.

Table 7.2
SUMMARY OF SHREDDER FLUFF DISPOSAL OPTIONS

Method	Advantages	Disadvantages[1]
Landfill in Municipal Site	• Historically, only economically feasible solution that was available.	• Landfill capacity shortages, high tipping fees have made this alternative less desirable.
Use as Municipal Landfill Cover Material	• Effective cover material in terms of stability, handling and spreadability. • Conserves soil used for cover, which could be used for other purposes.	• More work is required to determine the demand in Ontario and the willingness for landfill owners to use this waste. • Fluff must not be a designated hazardous waste.
Dedicated Landfill	• Potential exists for recovering waste if recycling becomes feasible available in future. • Low operating and maintenance costs.	• Large land area required. • Environmental assessment may be required, and some public opposition may be encountered.
Plastics Recycling	• Allows shredder fluff to be recycled into useful products.	• No economically feasible recycling routes at this time.
Hydrogenation	• Heat treatment of wastes would allow recovery of valuable fluff end-products.	• On-going research shows promise for future solution.
Pyrolysis	• Heat treatment of wastes would allow recovery of valuable fluff end-products.	• More research is required in this area to establish technologies and economics.
Incineration with Municipal Solid Wastes or Sludges	• Heat energy value of fluff would be a good fuel supplement for municipal incinerators. • New, dedicated incineration/energy recovery facilities would not be required.	• More work required to determine materials handling problems and ash characteristics.
Various Incineration Technologies	• Allows energy recycling of shredder fluff. • Incineration or subsequent vitrification produces non-leachable slag.	• All processes are still in theory or research stage. • For Ontario, ownership, operation, siting and environmental approvals would need to also be considered for an incineration facility.

Note:[1] All destruction oriented options have the disadvantage of loss of any further reuse.

Table 7.2 (Cont'd)
SUMMARY OF SHREDDER FLUFF DISPOSAL OPTIONS

Method	Advantages	Disadvantages
Use a Fuel Supplement in Cement Kilns	• Cement kilns are close to most shredders in Ontario. • Shredder fluff has been shown to be an effective fuel supplement in cement making. • Advantages include conservation of non-renewable resources, reduction or elimination in disposal costs for shredders, possible reduction in cement manufacturing costs.	• More work is require to determine economics in Ontario. • Interest of cement industry, materials handling needs and fluff pre-processing requirements must also be established. • Research indicates only course fraction of fluff can be used.
Designing for Recycling	• Ultimate reduction in wastes produced. • No toxic or hazardous contaminants would enter waste stream.	• Incentives must be created for manufacturers.

Chapter 8
SUMMARY OF FINDINGS

The main findings of this study of the feedstream materials and waste management and control alternatives available for the Ontario ferrous metal shredding industry are summarized below.

- Automobiles, white goods and some scrap steel components make up the feedstream to Ontario shredding facilities.

- Lead and cadmium in leachate extracted from shredder fluff, and total PCB content could potentially be high enough in some fluff samples due to the hetrogeneous nature of the material, to result in hazardous waste designation (Reg. 309).

- In automobiles, lead is present in batteries, battery cable clamps, lead wheel weights and exhaust trains from cars that used leaded gasoline. Both cadmium and lead were used in paints and coatings. Lead was used for body filler. Cadmium is no longer used in paints, coatings or fillers, while the use of lead is continuing to decrease.

- In white goods, some lead solder is used. Traces of lead and cadmium were used at one time in porcelain coating, but use has been discontinued.

- Small capacitors in white goods (primarily air conditioners, furnaces and refrigerators) manufactured before 1977 likely contain PCBs.

- If it is necessary to reduce the levels of the contaminants of concern in the fluff stream to meet disposal requirements, one of the following methods could be utilized:

  i) Removal of specific components from feedstream items prior to processing (ie. batteries, exhaust trains, PCB capacitors, etc.).

  ii) Treating the fluff to stabilize the contaminants of concern.

  iii) Screening of the fluff to remove particle fines containing a large portion of heavy metals.

  For determination of the most appropriate methods, and to allow better management of waste, routine characterization of representative samples using established techniques for sampling and leachate extraction are recommended.

- Due to landfill capacity shortages and rising tipping fees in Ontario, disposal alternatives to municipal landfilling of shredder fluff were discussed. The most feasible alternatives identified for Ontario were:

  i) Using fluff as landfill cover material.

  ii) Dedicated landfill.

  iii) Incineration in municipal solid waste or sewage sludge incinerators.

  iv) Use as fuel supplement in cement kilns.

  All of these alternatives would require some additional work to determine the applicability for the Ontario shredding industry from both the technological and regulatory approvals perspectives.

- A number of incinerator technologies show potential for energy recovery from shredder fluff. Some of these may be technologically feasible in the near future. However, economic feasibility as well as a number of non-technical issues (ie. siting and ownership) would need to be resolved prior to implementation in Ontario.

- Recycling and recovery alternatives that may be feasible in the future include mixed plastics recycling, hydrolysis and pyrolysis. Economic feasibility cannot be determined at this time.

- If manufacturers design for recycling in the future, the quantity of shredder fluff which requires disposal should begin to decrease.

APPENDIX A

Terms of Reference

TERMS OF REFERENCE

FOR A REPORT ON

THE FERROUS METAL SHREDDING INDUSTRY IN ONTARIO

INTRODUCTION

The Ontario Ministry of the Environment (MOE) and the Canadian Association of Recycling Industries (CARI) have been working together for some time to resolve common issues of concern for the benefit of the environment. The MOE recognizes the essential and beneficial nature of the ferrous metal shredding industry in providing a vitally needed service to the public by reducing the quantity of discarded material which would otherwise be destined for landfills.

Recently, leachate extraction and bulk analyses of a limited number of samples of shredder fluff wastes from ferrous metal shredding operations have indicated that the concentrations of certain heavy metals, such as cadmium and lead, as well as PCB, may be cause for concern. The results are inconclusive; however, the possibility that some of these wastes might be considered hazardous in accordance with Ontario Regulation 309 cannot be ruled out. The consequences of this decision would be serious to the industry, since much more shredder fluff waste would have to be diverted to specific disposal sites certified to receive hazardous wastes.

Samples of shredder wastes taken by MOE and the recycling and disposal companies have indicated that the leachate and bulk analyses are inconclusive, since the levels of contaminants are occasionally just marginally over the limit.

The issue of unshredded appliances or autos being deposited in landfills is an important one at this time, since landfill capacity is limited and many are reaching the end of their useful life. Because of the serious and immediate implications of these problems, the MOE and CARI have agreed that a study of the metal recycling industry should be undertaken by an independent consultant.

OBJECTIVES

The principle objectives of the study are as follows:

1. to identify and examine the various shredding operations, outlining the similarities and differences among the sites being studied;

2. to attempt to identify the sources of any contaminants by examining the materials being shredded (ie the feedstream), and

3. to review options for proper management of shredder wastes, utilizing existing or proposed technologies that are economically feasible.

STATEMENT OF WORK

1. Prepare a list of all ferrous shredding facilities in Ontario, including locations, contact persons, etc.

2. Prepare a methodology for statistically representative sampling of the feedstream (ie autos, white goods,etc.) that will address their heterogeneous nature.

3. Prepare a rationale to justify the number of samples and analyses to be considered representative for the materials being studied at each site.

4. Contact the appropriate sites and, with the permission of the owner, conduct inspections of the relevant ferrous shredder operations, collect details and document observations.

5. Take representative samples of the feedstream prior to shredding (including components of autos and white goods) likely to be the sources of contaminants in the waste streams from shredding operations.

6. If analysis of feedstream components is deemed necessary, submit the samples to a recognized laboratory (or laboratories) for bulk analyses and leachate analyses in accordance with the procedures in Ontario Regulation 309. The need for and extent of this task shall be reviewed with the Project Manager prior to any analysis being performed.

7. Based on the laboratory analyses, prepare conclusions regarding sources of contaminants i.e. white goods, autos, others, and also any sub-components of these groups. Identify any typical groupings and their associated wastes and contaminants.

8. Conduct a literature/telephone search of relevant waste management options (including recycling, reuse, treatment, disposal, etc.) in other jurisdictions in Canada, the USA and other advanced countries. New and up-coming technologies should also be investigated. Include any information on environmental regulations governing the management of shredder wastes in those jurisdictions.

9. Investigate and report on the delivery infrastructure serving the shredding operations. This should cover the entire scenario of handling autos and white goods, from the household to the shredding company.

10. Investigate and report on shredder technology in use at present and possible future improvements which might lead to reduced contaminants in the waste stream. Also, report on the possibility of incorporating higher recycling potential into new products destined for shredding at the end of their life cycle.

11. As a follow-up to Tasks 5, 6, and 7 report on the impact of past, present and future feedstocks on the characteristics of the waste streams from shredding operations.

12. Prepare recommendations for the proper management of shredder wastes utilizing existing and/or proposed technologies. The recommendations would also include the potential of any new methods which might be investigated in the near future.

13. Provide the documentation collected in Task 8 in a separate Appendix report for reference purposes.

PROJECT DIRECTION AND REPORTING

1. The Contractor will be required to meet with a joint committee of MOE and CARI personnel at the outset of the study to clarify the work program.

2. The Contractor will be asked to report to a joint committee of the MOE and CARI to ensure proper tracking of the project, according to a schedule designed for timely review.

3. The Contractor must document all assumptions and/or judgments used in preparing his conclusions and recommendations.

4. The Contractor must provide in his proposal a schedule for project completion, including significant milestones.

5. The Contractor shall present the final report to a joint committee of the MOE and CARI.

PROPOSAL EVALUATION CRITERIA

The proposals submitted in response to these Terms of Reference will be evaluated according to the following criteria in selecting the successful bidder:

- Understanding of the project

- Quality of the proposal

- Ability to achieve desired results according to the schedule and budget proposed

- Corporate and staff experience in similar projects

- Appropriate use of proposed staff skills

- Willingness to sign a "Letter of Agreement" (example copy attached)

- Absence of a conflict of interest

- Project cost including all fees and disbursements

APPENDIX B

Potential Incineration Technologies for Shredder Fluff

Appendix B
POTENTIAL INCINERATION TECHNOLOGIES FOR SHREDDER FLUFF

B.1 ROTARY KILN INCINERATION

In the rotary kiln process, wastes are fed to the kiln on a belt conveyer. The rotary kiln is refractory-lined steel cylinder mounted on rollers at a slight angle from the horizontal. It rotates as the wastes are injected into the higher, front end of the kiln. Fuel for firing the kiln is introduced, producing temperatures that range up to 1,100 °C. Residue is continuously discharged from the lower end of the kiln while gaseous combustion products exit into an afterburner chamber. The gases are then cooled and scrubbed before exiting the stack. Figure B.1 illustrates the rotary kiln process. The primary advantages of this process are:

- It is a commercially available and well established process.
- It has an excellent performance record.

Disadvantages of the process include:

- There are many moving parts, leading to high maintenance costs.
- Dry by-products (i.e. bottom ash, fly ash) may still be considered a hazardous waste.

The pilot study carried out by Woleman, et. al. (1986) used rotary kiln technology to incinerate approximately 3.2 tonnes of shredder fluff. A three day test burn was conducted using fluff from twelve U.S. shredder sites. The test results suggested that fluff is a suitable fuel for waste to energy applications. Approximately 94 percent of the combustibles were burnt out in the kiln. Self sustained combustion could be achieved and consistent energy value and ease of material handling enabled controlled heat release for controlled energy recovery. The initial fluff volume was reduced by 80 percent, and there was a 55 percent weight reduction, meaning 45 percent remained as ash. Air quality could be controlled to within regulatory limits with currently available technology. In this study, a bag house and packed tower scrubber were used for emission control.

A conceptual fluff to energy system was structured as part of Woleman et. al.'s study for an economic analysis. Based on known fluff disposal costs, energy costs and capital costs, it was found that automobile fluff as fuel is likely economically viable. However, costs for disposal of the large quantities of ash and electric power rates may require further investigation to determine payback on a site specific basis.

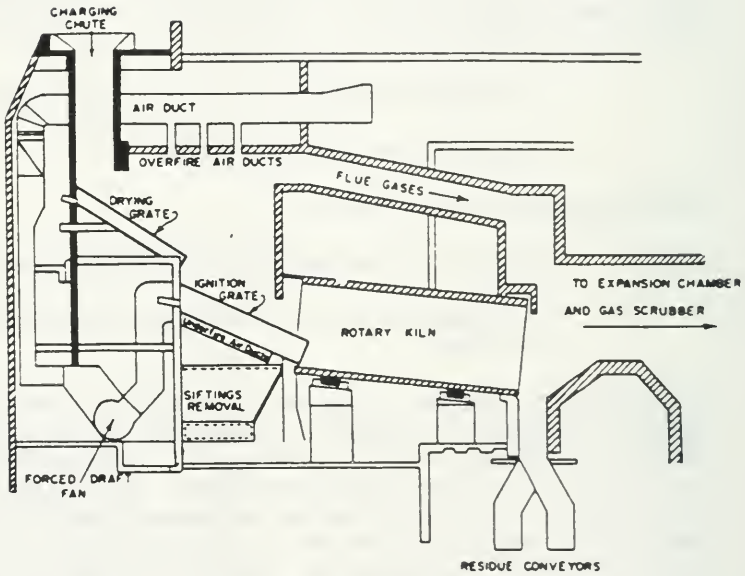

Figure B.1
ROTARY KILN INCINERATION PROCESS
Source: US EPA (1979)

Although this study demonstrated that there is potential for rotary kiln incineration of shredder fluff wastes, a number of limitations identified in the study indicated much more research and economic analysis remains to be done. The key limitations are listed below:

- Leachate tests were performed on the remaining ash. Although inconclusive, the results suggested that levels of lead may lead to hazardous classification of the ash. Processes are however available for treating ash to make it acceptable for landfilling. These processes are discussed later in this Appendix.

- Glass in the fluff may contribute to slagging problems in the incinerator. Solution of this problem may involve another sorting step prior to incineration.

- Either hazardous waste classification or pre-handling (i.e. sorting) of fluff will negatively effect the economics of an energy from waste scheme.

Pure Oxygen Incineration

Modification of waste incineration plants to use pure oxygen as incineration gas is a process that is patented in Germany. The main modifications to an existing plant is an up-stream air separation unit. One German plant has been reprocessing car batteries for some years using pure oxygen incineration (Menges, et. al., 1988).

The primary advantages of this type of process, outlined by Menges et. al., include:

- The furnace area and subsequent parts of the plant can be reduced to about one quarter of the previous size.

- Since the gas flow can be reduced, the flue gas cleaning is simplified and less NO_x and SO_2 are obtained.

- Because oxygen is highly reactive, the pollutants are immediately broken down and burned, or not formed at all; thus no dioxins are formed.

- It is cheaper to retrofit existing plants than to equip them with flue gas cleaning units.

B.2 FLUIDIZED BED INCINERATION

A fluidized bed incinerator is a vertical, refractory-lined steel structure containing a bed of inert granular material. The inert material, usually sand, is fluidized by injection of

air into the bottom of the bed through a perforated plate. Once the bed is heated to the correct operating temperature for combustion, liquid or solid waste is injected into or above the bed. Supplementary fuel, to maintain combustion, is fed directly into the bed or above the bed, and/or is fired in the windbox. Combustion product gases are scrubbed before release to the atmosphere.

A variation of fluidized bed technology is circulating bed combustion (CBC). The circulating bed system increases turbulence by the use of high air velocity. Because of the high air velocity, solids are entrained and combustion takes place along the entire height of the combustion section, increasing throughput per unit area.

The primary advantages to fluidized bed incineration systems include:

- The design is simple and compact, and there are no moving parts in the combustion zone.
- Autogenous combustion can be achieved for wastes with lower net heat content than with other incineration technologies.
- The relatively low gas temperatures and excess air requirements minimize NO_x formation.

The primary disadvantages associated with fluidized bed systems are:

- It is a relatively expensive incineration technology to operate.
- Inorganic materials may cause bed degradation.

Energy Products of Idaho (EPI) (Albertson, 1989) conducted extensive testing of the fluidized bed system for shredder fluff in a pilot plant. As a result of this testing, a unique fluidized bed system was developed for shredder wastes. Figure B.2 presents a schematic of the testing plant.

The 1989 paper (Albertson) presented preliminary results from emissions testing. Approximately 21 tonnes of shredder fluff from several different facilities was used for the emissions testing. Monitoring of oxygen, carbon monoxide, sulphur dioxide and NO_x was continuous over the study period, which ran for 9 days. Because of the potential for acid gas emissions, limestone was added with the fluff on a continual basis. Final emission data were not available at the time of report writing.

Subsequent to this report, EPI prepared a proposal to a major U.S. auto shredder to design, build and operate a 7.5 MW electrical plant using a fluidized bed combustion system to burn shredder fluff, which would consume a reported 80,000 tonnes of shredder fluff annually (Schmitt, 1990).

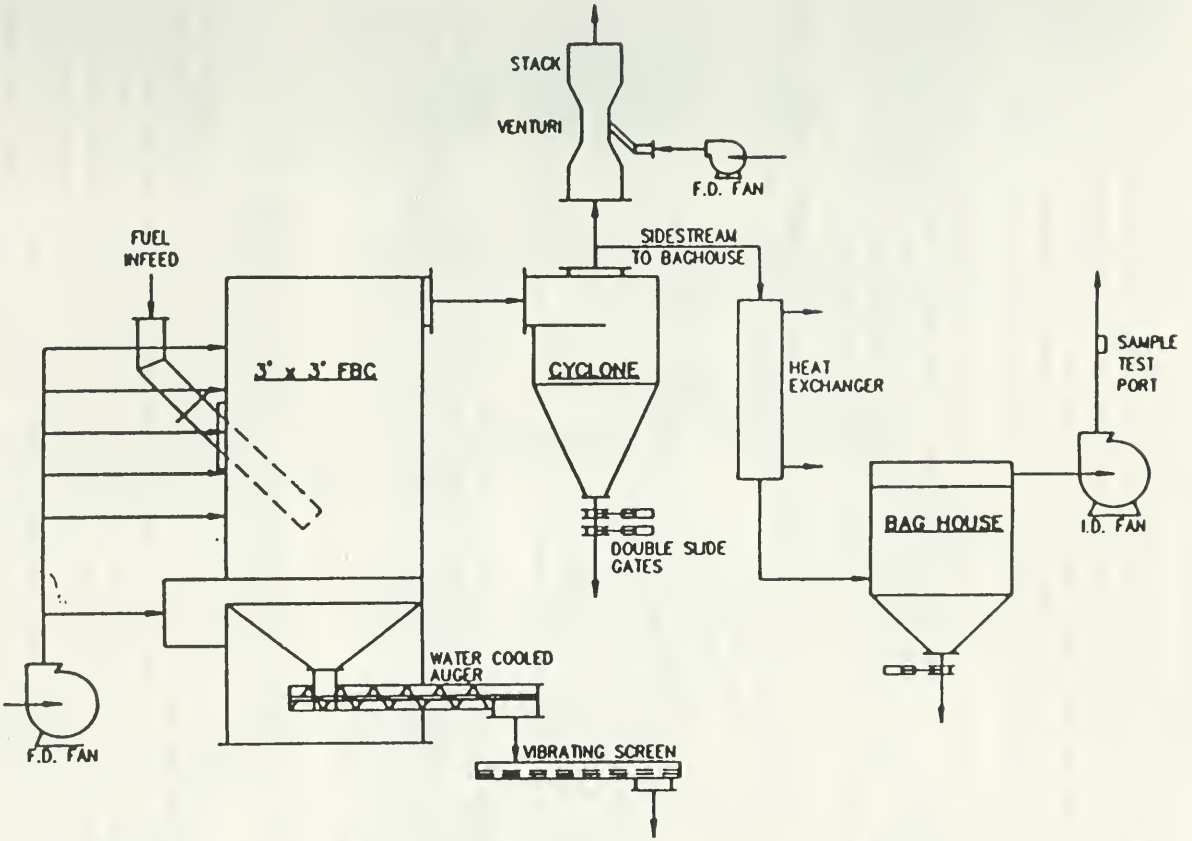

Figure B.2
FLUIDIZED BED COMBUSTION SYSTEM
FOR SHREDDER FLUFF
Source: Albertson (1989)

B.3 PLASMA INCINERATION

Incineration of solid wastes using electrical energy in the form of plasma has been considered a potentially efficient means of decontaminating hazardous waste. This type of process involves heating the waste material either directly or indirectly to combust the waste materials, and volatilize and thermally destruct the organic contaminants. Temperatures obtained are sufficiently high for non-combustible materials to become molten. The molten material solidifies into a vitrified mass which is non-leachable.

Retech, Inc. of California, has developed the Plasma Centrifugal Reactor (PCR), shown in Figure B.3. The three phase development of this furnace demonstrated successful volume reduction of radioactive mixed wastes and contaminated soil and hydrocarbon mixtures. It was concluded from the development tests that heavy metals and organic wastes could be treated with favourable results (Eschenbach et. al., 1989).

The 1990 CMP report (Schmitt) indicated that the U.S. Department of Energy (DOE) is operating a Retech PCR unit in Butte Montana, and that there is interest in conducting tests with automobile fluff.

The U.S. Electric Power Research Institute (EPRI) and Westinghouse Electric Power Corporation have developed a plasma-fired cupola for melting iron independent of coke combustions (EPRI, 1988). This plasma cupola has been tested for treatment of landfill material. Results indicate that vitrification of this type of material is feasible. Westinghouse personnel expect that the plasma process would combust shredder fluff and produce a glassy slag that would excapulate any hazardous metals (Schmitt, 1990).

An electric furnace facility (EFF) has been constructed adjacent to the Lakeview Thermal Generating Station by Ontario Hydro for research and development in the area of metallurgy. The facility has been designed to be as flexible as possible to accommodate a variety of projects. Testing of plasma incineration of shredder fluff is possible at this facility, and could be considered as a potential research and development project (Simpson, 1990).

B.4 HIGH TEMPERATURE GASIFICATION PROCESS

A high-temperature gasification (HTV) process has been patented by VOEST-ALPINE Industrieanlagenbau Ges.m.b.H in Germany (Freimann, 1989). The process, illustrated in Figure B.4, has preheated air and a primary fuel fed into the gasifier combustion chamber, where the temperature reaches about 1,600 °C. Slag from the chamber is discharged into a waterbath where it solidifies into a fine-grained vitreous mass. The gas produced flows through a coke bed, where entrained dust is removed and catalytic reactions take place. The outlet gas is about 900 °C, and does not contain any considerable traces of condensable hydrocarbons. The gas is contaminated by dust, chloride, fluoride, sulphur, as well as volatile heavy metals (Pb, Hg, and Zn). Prior to gas

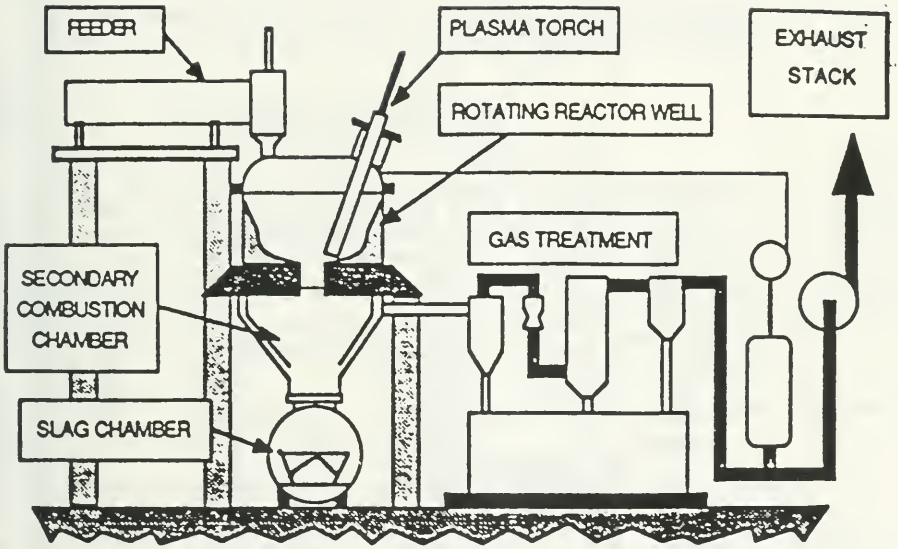

Figure B.3

RETECH PLASMA CENTRIFUGAL REACTOR

Source: Eschenbach et. al., (1989)

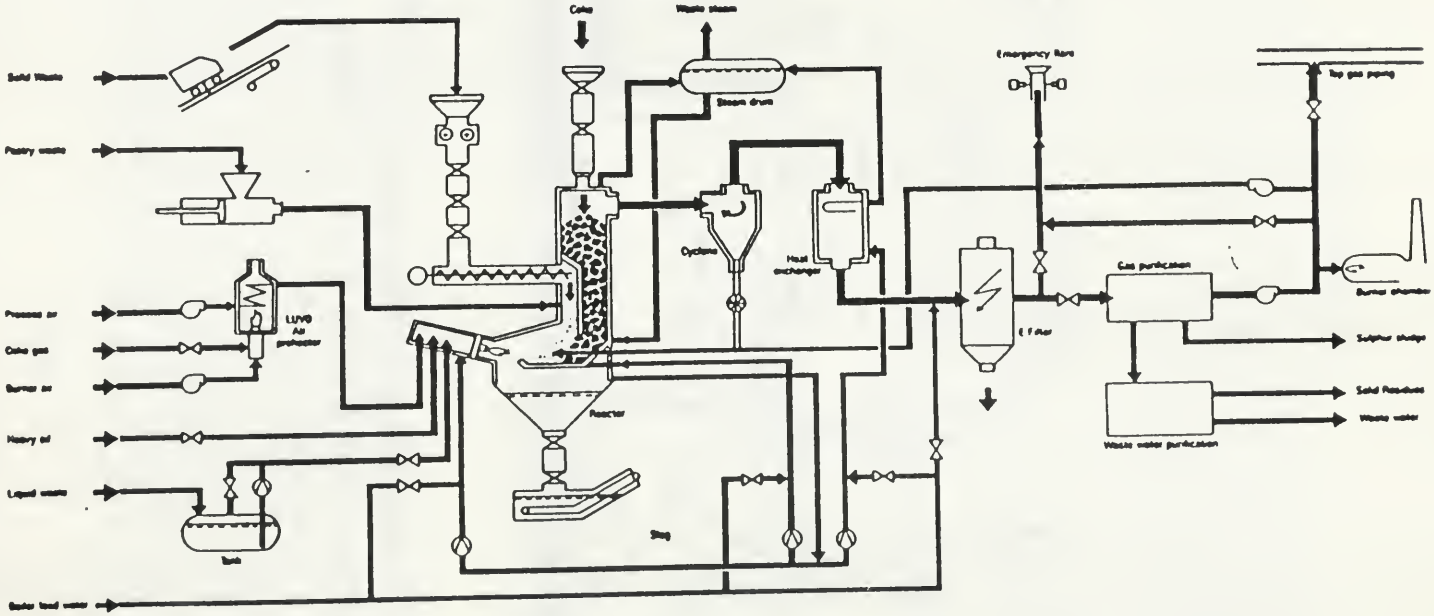

Figure B.4

VOEST-ALPINE HIGH TEMPERATURE GASIFICATION

Source Freimann, Staudinger (1988)

purification, heat is used for steam generation. A simple scrubber is then used to remove contaminants and a Sulfint-plant removes hydrogen sulphide and converts it to elementary sulphur.

The resultant gas has an energy value of 3,200 kJ/Nm^3, and complies with all environmental emission regulations.

VOEST-ALPINE has demonstrated the use of their HTV process for processing shredder fluff. For this test, fluff mixed with mixed plastics were agglomerated into briquettes, which were fed into the reactor. The results indicated that the mixed fluff/plastics waste could be incinerated in the HTV process, resulting in the production of a clean fuel gas and stable slag. This process is presently being offered for sale.

B.5 SUBMERGED ARC MELTING

The deTOX$_{TM}$ Process was discussed in the CMP report (Schmitt, 1990) as a potential technology for combustion of automobile fluff, producing a vitrified product which encapsulates the heavy metals. Reportedly the vitrified glass/ ceramic type product can be converted to tiles or bricks etc. The CMP report indicated that this process, although showing potential for fluff incineration, would be particularly suited for processing hazardous ash from other incineration processes (ie. rotary kiln, fluidized bed, etc.). Figure B.5 illustrates this application.

Cold-top submerged arc melting is used in the deTOX$_{TM}$ process. Some major characteristics of the process include (Schmitt, 1990):

1. High energy efficiency and low operating costs.

2. Low volatilization of metals, and high metal capture efficiency by vitrification.

3. Low plan area and therefore suitable for retro-fitting to existing incineration units.

4. Low capital costs. If gases are not ducted to an incinerator, only a very small baghouse is needed.

A pilot/demonstration unit of the deTOX$_{TM}$ unit is being constructed in the U.K. The process has been proven in experimental work which involved melting tonnage quantities of waste to produce floor tiles.

Resorption Canada in Ottawa, Ontario has a pilot scale submerged arc facility that could be used for testing using shredder fluff (Simpson, 1990).

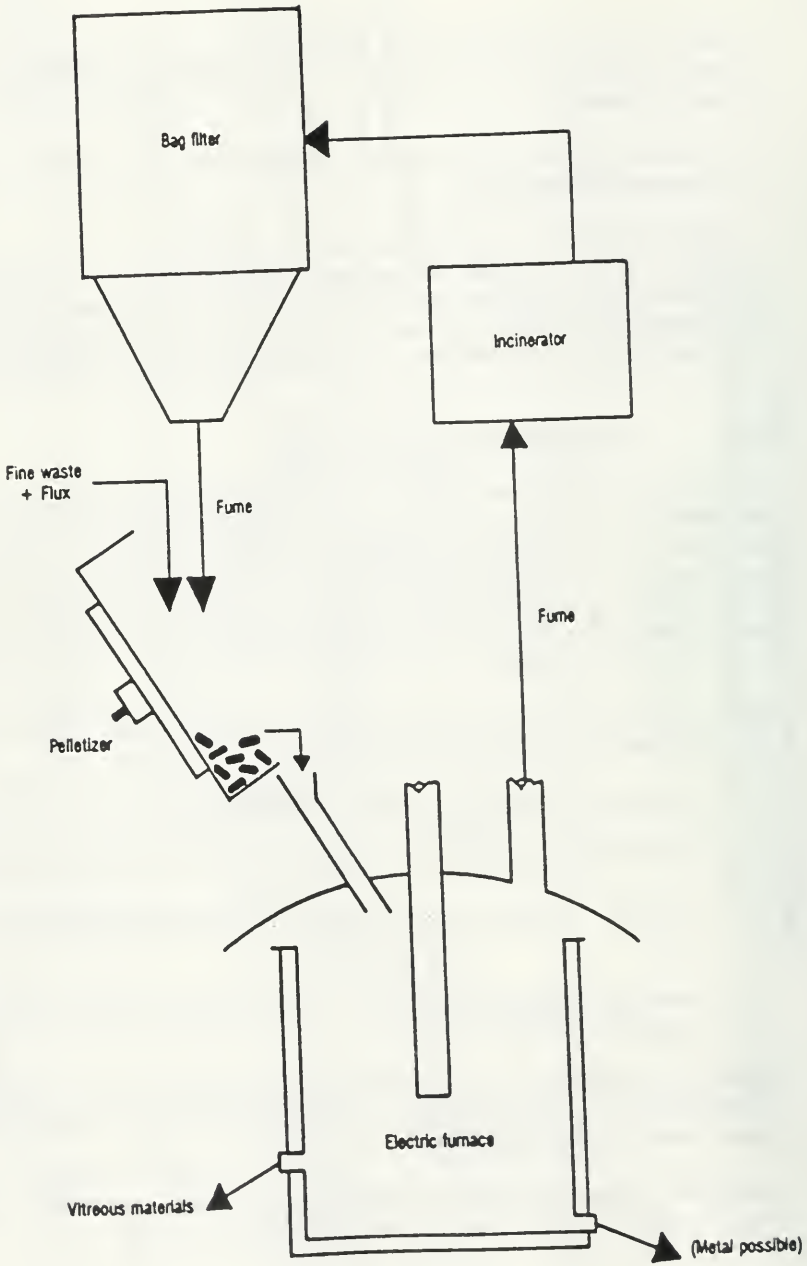

Figure B.5
deTOX$_{TM}$ PROCESS
Source: Schmitt, (1990)

B.6 PUREMET PROCESS

A patented hydrometallurgical process for the removal of non-ferrous metals from steel scrap developed by Puremet in Tennessee could possibly be used to remove metals from ash resulting from shredder fluff incineration (Schmitt, 1990).

The process, illustrated in Figure B.6, involves the dissolution of non-ferrous metals in the waste using a cuprous ammonium sulphate solution. The metal rich solution goes to electrowinning cells to recover copper, zinc, nickel etc. The metal rich solution can also be sent to be refrigerated to allow chrystallization of copper salts.

Puremet indicate that incinerator ash could be treated in the process much the same as scrap (Schmitt, 1990)

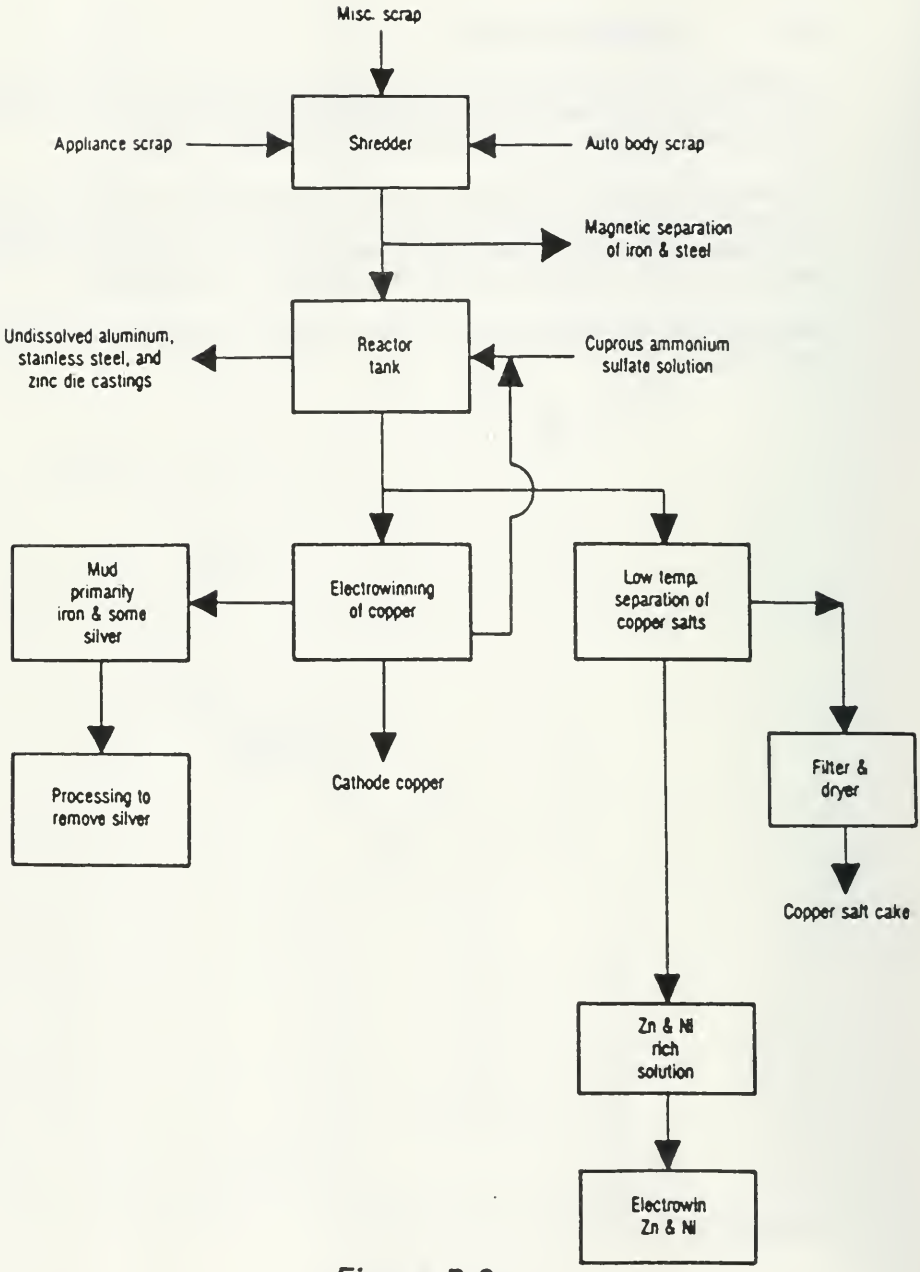

Figure B.6
PUREMET PROCESS
Source: Schmitt, (1990)

APPENDIX C

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